A PRELIMINARY EXAMINATION OF AGING AND SEX ON DICHOTIC LISTENING PERFORMANCE

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requirements for the Degree of

Master of Audiology

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Table of Contents

List of Figures

List of Tables

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Abstract

Dichotic listening of auditory stimuli is a method of assessing brain lateralisation. Different stimuli are presented simultaneously to the left and right ears, with the listener reporting which stimulus is perceived most clearly. To date, several studies that have examined the effects of aging on dichotic listening performance have indicated a pronounced right ear advantage (REA) with increasing age, but few studies have considered the effects of sex, and findings to date have been inconclusive. The aim of this research was to investigate whether the effects of age and sex resulted in a difference in the magnitude of the REA in both undirected and directed attentional tasks. Forty sex-matched, right-handed subjects with normal hearing or symmetrical bilateral sensorineural hearing loss participated in a series of directed and undirected dichotic listening tasks using consonant-vowel (CV) stimuli. The interaural intensity difference (IID) was modulated randomly during the undirected attention task. Results indicated that all groups (age & sex) showed a REA for both undirected and directed dichotic listening tasks. No age or sex-related differences were found. The findings were suggestive of a task-linked effect for dichotic listening performance. The use of CV stimuli, in combination with detailed testing via manipulation of the IID, appeared to minimize any possible age or sex-related differences. These findings have implications for theories on laterality and hemispheric asymmetry for older adults.

Keywords: dichotic listening; right ear advantage; aging; sex; lateralisation

Introduction

Dichotic Listening

Dichotic listening is a non-invasive technique used to assess brain lateralisation and asymmetry when processing speech and non-speech auditory signals. Dichotic listening literally means listening to two different signals simultaneously, with one presented to the left ear, and the other to the right (Hugdahl, Westerhausen, Alho, Medvedev, & Hamalainen, 2008a). Depending on the type of acoustic stimuli presented to the listener, an "ear advantage" has been found, with the signal presented to one of the ears perceived as more dominant. Studies have shown that when speech stimuli, such as digits, are simultaneously presented to both ears, there is a right ear advantage (REA). In other words, when participants are asked to report back what they heard, the signal presented to the right ear is more readily perceived (Kimura, 1961; Hugdahl et al., 2008a).

The Right Ear Advantage (REA)

The earliest research on dichotic listening was carried out to ascertain digit span recall in patients undergoing surgery for lesions located in various parts of the temporal lobe (Kimura, 1961). Chains of digits were presented to both ears simultaneously before and after surgery, with findings indicating higher scores for the right ear preoperatively, regardless of the site of lesion. Findings also indicated lower overall recall scores postoperatively for those who had lesions in the left temporal lobe compared with those who had lesions in the right temporal lobe. Kimura (1961) found that for those with speech represented in the left hemisphere of the brain (typically right-handed individuals), the right ear is more efficient for perception of speech, regardless of site of lesion. She termed this effect a right-ear advantage (REA). The findings were strengthened by the presence of a small control group without brain lesions, who also showed a strong REA. Kimura (1961) put forward several ideas to explain the cause of the REA she observed. The first is that input to one ear is most strongly represented in the hemisphere of the brain contralateral to that ear. The second is that the left temporal lobe has a specialised role in recognising auditorily-presented verbal information and language processing, based on the location of Wernicke's area. Kimura suggested that the right ear was more strongly or directly connected to the left temporal lobe, resulting in verbal material being transmitted more reliably to the speech and language centres in the left hemisphere via this pathway. She also suggested that input to the left ear went directly to the contralateral right hemisphere and had to be transferred via the corpus callosum to the language processing centres in the left hemisphere (i.e. Broca's and Wernicke's areas). Kimura hypothesized that this resulted in a slight delay in speech processing, thus explaining the REA. Kimura did not control for the effects of peripheral hearing sensitivity or age in her participants.

Since Kimura's study in 1961, the effects of various speech and non-speech stimuli have been investigated, with speech-stimuli including sentences (Jerger, Chimel, Allen, & Wilson, 1994), digits (Bellis & Wilber, 2001) and consonant-vowel (CV) stimuli (Studdert-Kennedy & Shankweiler, 1970; Tallus, Hugdahl, Alho, Medvedev & Hamalainen, 2007). Non-speech stimuli have included melodies and tones (Kimura, 1967). Research has shown that the use of linguistic CV stimuli simultaneously presented to both ears results in a significant REA. In other words, when participants are instructed to report which CV pair they heard most clearly, the signal presented to the right ear is more readily perceived (Asbjornsen & Helland, 2006; Hugdahl et al., 2008a; Tallus et al., 2007).

The Left Ear Advantage (LEA)

A seminal study by Kimura (1967) found that when non-speech stimuli such as melodies are presented to both ears simultaneously, a left ear advantage (LEA) is found. In this study, two different melodies were presented simultaneously to each ear, and participants were instructed to pick which two they heard from a group of four. Results showed there were more correct identifications for melodies presented to the left ear compared to the right. Kimura interpreted the findings to indicate a dissociation of auditory asymmetries depending on stimulus type, with these asymmetries reflecting the functional differences of the two hemispheres of the brain. The presumed predominance of the right temporal lobe in integrating melodic patterns is reflected in the LEA. Since this early work, other studies have corroborated the finding that the presentation of non-speech stimuli simultaneously to both ears, such as environmental sounds and tones, results in a LEA (Spajdel, Jariabkova & Riccansky, 2007). Spajdel et al. (2007) found that in 60 right-handed participants (35 males and 25 females) both two-tonal sequence and environmental sound dichotic listening tasks resulted in a LEA. A REA was observed for CV syllables. These findings were consistent for musicians (n=33) and non-musicians (n=27). This is of importance as it is assumed that musicians are likely to be more experienced to listening to musical stimuli. As this factor had no effect, findings were attributed to a mechanism independent of musical experience (i.e. right hemisphere dominance for the processing of non-verbal stimuli).

Models of REA

Attempts to explain the REA have been made using two prominent theoretical models regarding the processing of verbal information. Both models implicate the role of the corpus callosum, the commissure connecting the left and right hemispheres of the brain (Suganthy, Raghuram, Antonisamy, Vettivel, Madhavi & Koshi, 2003). The first theory is the structural model proposed by Kimura (1961) and the second is the attentional model proposed by Kinsbourne (1970).

Structural Model

Kimura proposed the structural model of dichotic listening, based on the interaction of cerebral laterality. She proposed that signals from the cochlea were presented to the auditory cortex in both the ipsilateral and contralateral cerebral hemispheres, but more strongly in the contralateral hemisphere. Accordingly, the REA reflects this asymmetric ascending input of auditory information to the temporal lobe of the brain. Input to the cochlea of the right ear projects to the auditory brainstem structures. It then ascends, via contralateral connections through the thalamus, to the left temporal cortex. This is where the language centre is located in the majority of right-handed people (Knecht, Drager, Deppe, Bobe, Lohmann, Floel, Ringelstein & Henningsen, 2000). On the other hand, input to the left cochlea reaches the right hemisphere first before crossing, via the corpus callosum, to processing areas in the left hemisphere. As a result of this interhemispheric transfer, some information is lost or delayed. The structural model holds that the interaction of these symmetrical anatomical connections and a left-hemisphere advantage for processing language influences performance in dichotic listening tasks and results in the REA. This right ear bias, induced by a left hemisphere processing advantage for verbal information is often referred to as a *bottom-up process,* and is seen in both males and females (Hirnstein, Westerhausen, Korsnes & Hugdahl., in press). This concept is illustrated in Figure 1.

Kimura's hypothesis of such asymmetry in the right and left auditory cortices during dichotic listening with verbal stimuli such as CV syllables is supported by a magnetoencephalogram (MEG) study by Penna et al. (2007). MEG is an imaging technique examining activation of different regions of the brain. In this study, the authors looked at activation of the primary auditory cortices in response to dichotic CV stimuli in a small sample of healthy participants (n=10). This sample was not matched for age, sex or handedness. The REA was shown physiologically via inhibition of the ipsilateral pathway to the left hemisphere in all participants, thus favouring input from the right ear. Ipsilateral and contralateral pathways were inhibited to the same extent in the right hemisphere. This physiological evidence provides strong support that the right ear is the advantaged one, because input reaches the left, language dominant hemisphere via a preferential route, which suppresses the left ipsilateral pathway.

Bottom-up processing of dichotic listening has also been investigated according to sex differences. Weekes, Zaidel and Zaidel (1995) examined polar sex (male vs. female) and spectral sex (masculinity vs. femininity) differences on hemispheric lateralization using a CV syllable dichotic listening task. Results, calculated in percentage correct for each ear from the sex matched sample of 30, showed no significant differences across groups. This suggests that both sexes and sex-roles process speech information in a similar way. The authors suggested that any differences in dichotic listening would likely be from differences in laterality rather than polar or spectral sex.

In summary, the structural model of dichotic listening is based on the interaction of cerebral laterality, with the signals from the cochlea being projected to the auditory cortex in the ipsilateral and contralateral cerebral hemispheres, but more strongly in the hemisphere contralateral to the stimulated ear. Therefore, there is an advantage for speech signals presented to the right ear to be transmitted immediately and directly to the language areas in the left hemisphere. This effect is found in males and females of all ages. Signals presented to the left ear have been reported to be delayed in being transmitted to the language areas in the left hemisphere as they must be transmitted via the corpus callosum before being processed (Westerhausen & Hugdahl, 2008), thus explaining the REA.

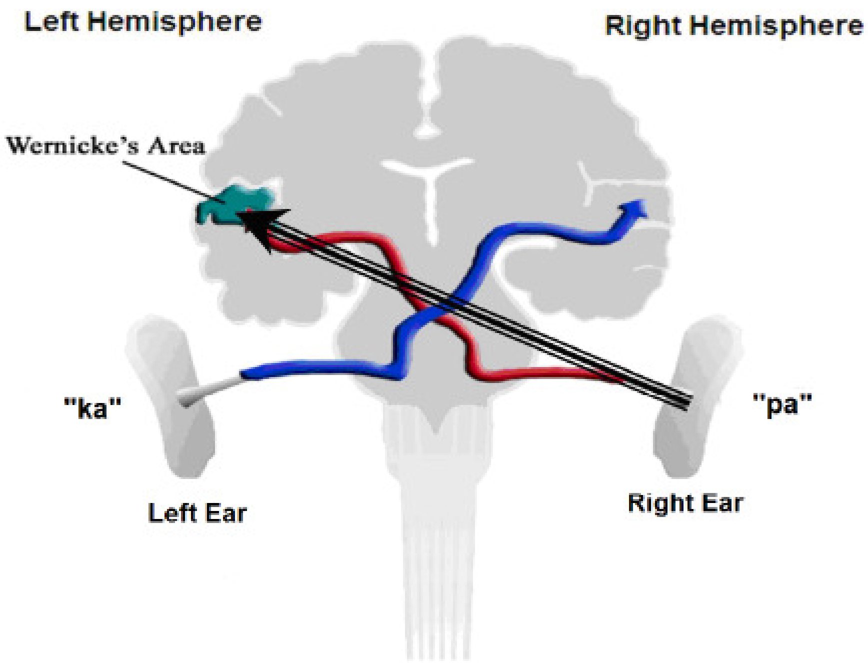

Figure 1. Physiological depiction of bottom-up processing and a right ear advantage (REA) for the perception of “pa” during an undirected dichotic listening task. Messages from the right ear are directly sent to Wernicke’s area, which is important for processing language. The left ear is projected to the right hemisphere and must then cross, via the corpus callosum, to the language region of the brain (revised from Marek, 2008).

Attentional Model

The second model of dichotic listening considers the role of attention during a listening task. Kinsbourne (1970) believed that Kimura's reports of REA could not be explained entirely by bottom-up processing. Kinsbourne was likely the first author to examine the effects of attention on dichotic listening. He aimed to determine if directed attention in regards to speech stimuli enhanced or decreased the REA found in previous dichotic listening studies, by preferentially activating the left, language dominant hemisphere. Each hemisphere primarily attends to the contralateral ear (Kimura, 1961). Thus, Kinsbourne hypothesized that the REA may be 1) enhanced by priming the left hemisphere to anticipate speech, and 2) suppressing presentations to the left ear due to this anticipation, both resulting in the REA. This process of anticipation by the left hemisphere for speech stimuli is referred to as *top-down* processing. The concept is illustrated in Figure 2.

Several studies have examined the effects of attention on the REA (Hugdahl & Anderson, 1986; Jerger et al., 1994). Hugdahl and Anderson (1986) compared instances of a LEA when deliberately attending to the right ear, and a REA when deliberately attending to the left ear during a CV recall dichotic listening task. If a REA was found during a directed-left task, it would indicate that attention alone could not explain the REA. Findings showed that significantly more recall of dichotic CV stimuli came from the ear that was attended to in adults, indicating that the REA can be enhanced when attending to the right ear and reduced when attending to the left ear. However, findings also showed that there was still better recall from the unattended right ear, or a significant REA overall, meaning attention alone cannot explain the phenomenon.

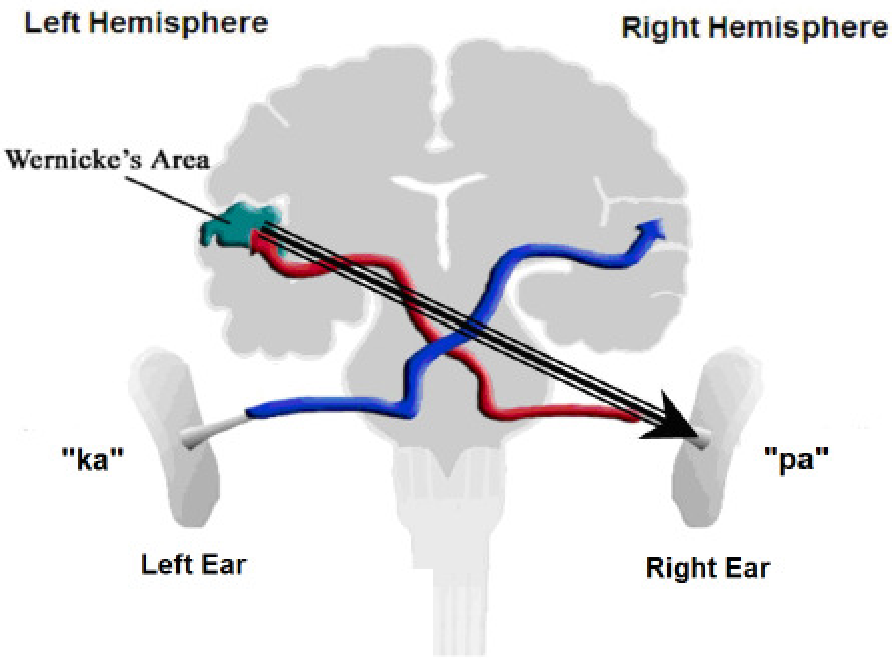

Figure 2. Physiological representation of a REA for “pa” during a directed attention listening task. When deliberate attention is placed on listening for language, the language area in the left hemisphere (Wernicke’s Area) anticipates speech, with the direct pathway being more dominant in the right ear for the processing of speech such as CV syllables (revised from Marek, 2008).

There is also some physiological support for the attentional model, with a study by Hugdahl, Law, Kyllingsbaek, Bronnick, Grade and Paulson (1999) using the positron emission tomography (PET) technique to evaluate cortical activation during presentations of dichotic stimuli. The PET technique is a form of neuroimaging used to study changes in regional neural activity, indexed as regional cerebral blood flow (rCBF) in the critical brain areas during different tasks. Twelve right-handed males participated in the study. The authors manipulated the stimuli presented (CV syllables and musical instruments) and the direction participants attended. In the "attend both ears" condition, participants were asked to attend to both ears, and press a button when they detected a target stimulus. In the "attend left ear" condition, they were instructed to attend to the left ear and press a button when they heard the target in that ear. In the "attend right" condition, they were instructed to focus on the right ear and press a button when they detected the target in the right ear. For each of the three attentional conditions, they were told before the scan commenced that they were listening for a specific target stimulus. Results showed greater cortical activation over the contralateral parietal lobe. For speech stimuli, when attention was directed to the left ear, activity increased over the right hemisphere and vice versa. The results also indicated a REA when participants attended to both ears (undirected attention), and when they attended to the right ear. The former indicates that directing attention can enhance the processing of speech stimuli in the attended ear (i.e. top-down processing), while the latter finding provides more support for the bottom-up model of processing, suggesting an ear advantage in this condition is not attentional, but rather related to speech language dominance and crossed auditory pathways. A LEA was seen in the "attend left ear" condition. For musical stimuli, participants displayed a LEA for the "attend both ears" condition, however no significant differences were found in either of the directed attention conditions.

Foundas, Corey, Hurley and Heliman, (2006) used binaural CV stimuli to determine whether left- and right-handed participants differed in undirected and directed dichotic listening tasks. The authors also examined the effect of ear report instructions on dichotic listening performance. Binaural presentation of CV syllables revealed a robust REA when individuals reported what they perceived on each trial when attention was undirected, and this REA was more robust when attention was directed toward the right ear. There was a LEA when attention was directed toward the left ear. These patterns were seen in males and females and indicate the ability to modulate the strength of the REA by manipulating attention. The results also revealed that the relationship between attention and change in lateralisation (directed vs. undirected) was significantly different for left- and right-handed people.

The findings of Foundas et al. (2006) show that directing attention can enhance the processing of binaurally presented speech stimuli in the attended ear. The authors concluded that there must be a number of explanations for the REA including 1) anatomical organization, 2) perceptual effects and 3) cognitive operations. According to the attentional model, right-handed listeners have a greater rightward attentional bias than left-handers, so in the directed-left attentional condition, right-handers may show a greater right-to-left reversal of their natural bias (i.e. a greater modulation of the REA from the undirected to the directed attention condition). In contrast, left-handers may show less of a rightward bias in the undirected attention condition compared with right-handers, and so in the directed-right condition, left-handers may have a greater shift in laterality compared with right-handers. These findings support the model that attention increases the salience of the stimuli occurring at the directed location, and directed listening to the left ear may override the right-sided attentional bias induced by auditory verbal information, which selectively activates the left hemisphere.

Hugdahl, Carlson, and Eichele (2001) used a shared database of the Nordic Centre of Excellence Consortium, consisting of 1500 healthy individuals aged 5-89 years, to assess the effects of top-down attention modulation on the magnitude of the REA. When participants were instructed to focus on their right ear, the REA was significantly increased, and when they were instructed to focus on their left ear, the REA was significantly decreased, often to the point of shifting to a LEA. The authors concluded that focusing attention to the right or the left ear modulated the strength of the REA.

In summary, the attentional model assumes that anticipation of incoming verbal signals serves to activate the left hemisphere, where a priming effect occurs for subsequent processing. This activation is automatic and results in a bias favouring the left hemisphere and therefore the contralateral right ear. This allows acoustic information in the right ear to be processed faster, as seen with a higher number of right ear reports (Westerhausen & Hugdahl, 2008). Directing attention to the right ear increases the magnitude of the REA, whilst directing attention to the left ear can decrease the magnitude of the REA, or cause a shift to a LEA (Hugdahl et al., 2008b; Westerhausen & Hugdahl, 2008).

Interaural Stimulus Intensity Differences

Berlin et al. (1972, 1973) were the first to report that the magnitude of the REA to CV stimuli could be modulated by amplitude or phase shifts. Since then, several dichotic listening studies have also shown that the magnitude of the REA can be manipulated by altering the intensity level of the signal presented to each ear (Tallus et al., 2007; Westerhausen, Moosmann, Alho, Medvedev, Hamalainen & Hugdahl, 2009), as well as by altering the phase of the presented stimuli (Ozgoren, Bayazit, Oniz & Hugdahl, 2012). Tallus et al. (2007) carried out a study with the aim to modulate the magnitude of the REA by manipulating the interaural intensity difference (IID) between the right and left ear inputs, thus giving higher intensity speech sounds a greater chance of being processed, regardless of the ear they were presented to. Twenty right-handed participants (13 females and 7 males) completed a dichotic listening task, in which the IID was systematically varied. One third of trials were of greater intensity in the left ear, one third of greater intensity in the right ear, and one third were of equal intensity in both ears. Results showed that by manipulating the IID, the magnitude of the REA was also altered. The authors suggested that modulating the magnitude of the REA could be a means of exploring and quantifying impairments in speech processing in a clinical context, such as patients with schizophrenia. Interestingly, the REA cannot be so successfully manipulated in patients with schizophrenia (O Leary, 2003).

Hugdahl et al. (2008b) also investigated the effect of altering the IID in healthy participants, using dichotically presented CV syllables. By gradually increasing the IID in decibel (dB) increments, the authors examined the minimum intensity difference required to shift a REA to a LEA. A total of 33 participants completed an undirected listening task, whereby the IID was modulated with either the left or right ear being more intense. Data were analyzed in an intensity difference (15 steps) x ear (left or right) repeated measure analysis of variance (RM-ANOVA). Results indicated a clear REA at 0 dB (i.e. no IID between the right and left ear intensities). When the intensity was modulated to favour the left ear, a REA persisted until the interaural asymmetry was 9 dB more intense in the left ear, indicating a preference for selecting speech presented to the right ear up until a sound pressure level IID of 9dB. Once the stimulus becomes ≥ 9 dB louder in the left, a LEA is seen.

In summary, it is possible that altering the IID can manipulate the strength of the REA. Altering IIDs between the levels presented to the left and right ears when attention is undirected appears to alter the magnitude of the REA. This is reflective of changing the bottom-up process, giving the higher intensity speech sounds a better chance of being processed, irrespective of which ear they are presented to. Alterations to the IID levels presented to the left and right ears when attention is directed have also been found to alter the magnitude of the REA, indicating an effect on top-down processing. The interaction of these two models of processing reflects participation of both hemispheres in the transfer of information.

Dichotic Listening and Aging

It is widely accepted in the field of audiology that elderly persons tend to have more difficulty understanding speech than their younger counterparts, especially in the presence of background noise (Bellis & Wilber, 2001). While this is partly linked to a decline in peripheral hearing sensitivity, there is research to suggest that declines in central auditory processing and cognition also have a role to play (Martin & Jerger, 2005). There are reports of a more pronounced REA with increasing age (Hirnstein et al., in press; Bellis & Wilber, 2001; Jerger et al., 1994), however the exact neural mechanisms contributing to this interaural asymmetry remain controversial, with evidence for both the bottom-up (Kimura, 1961) and the top-down (Kinsbourne, 1970) models of dichotic listening. Neither model entirely explains the aural asymmetries observed with age, hence it is now thought that age-related deficits in interhemispheric processing of information may underlie the listening problems seen in the older population (Martin & Jerger, 2005). Several models have been described in an attempt to explain the links between hemispheric asymmetry and the REA in aging. Dolcos, Rice and Cabeza (2002) summarise two of these: the right hemisphere aging model put forward by Brown and Jaffe (1975) and the hemispheric asymmetry reduction in older adults (HAROLD) model, outlined by Cabeza (2002).

Bellis and Wilber (2001) used dichotic listening among other measures to investigate the effects of age and sex on interhemispheric function across the lifespan of healthy, right handed adults with symmetrical hearing. A total of 120 participants were divided into four sex-matched age groups (20-25 years, 35-40 years, 55-60 years and 70-75 years). There were 15 males and 15 females in each group. These age ranges were chosen to account for the effects of menopause in the female participants, however this resulted in the age ranges being non-continuous, so it is not possible to determine at exactly what age the change in hemispheric symmetry took place. Participants were required to listen to dichotically presented digits in an undirected attention paradigm, and repeat the four digits they heard. Scores were calculated as the percentage correct per ear. An index of interhemispheric integrity was then calculated by subtracting the left ear percentage score from the right ear percentage score, yielding a measure of the REA. There were some constraints placed on memory, with participants having to recall four digits, so the impact of cognition on these findings must be considered as it is well known that working memory declines with increasing age (Light & Anderson, 1985; Hallgren, Larsby, Lyxell & Arlinger, 2001). Results from Jerger et al. showed that for males and females, right and left ear performance on the dichotic listening task decreased with increasing age, with the decrease in left ear performance being significantly worse than right ear performance, leading to an increase in the REA magnitude with increasing age. The authors interpreted their findings to indicate that binaural processing decreases with increasing age. They also reported that an increase in the size of the REA with aging occurred earlier in males than females, which will be discussed later.

These findings of a greater REA magnitude with aging are consistent with an earlier, retrospective study by Jerger et al. (1994). Findings indicated a progressively larger REA or left ear disadvantage with increasing age on undirected and directed dichotic sentence tasks. In the undirected attention paradigm, the participants reported what was heard in both ears, while in the directed attention paradigm, the participants reported only what was heard in one pre-cued ear. In half the trials the right ear was pre-cued and in the other half, the left ear was pre-cued. As with Bellis and Wilber (2001) it is possible that there were strains on memory in this task, with participants having to recall at a minimum an entire sentence which introduces a significant cognitive demand. This may have affected the results, especially in the older age groups. A total of 356 participants (203 males and 153 females) were divided into 7 age groups with varying numbers of participants in each age group (9-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, 70-79 years and 80-89 years). Handedness was not controlled. Results indicated an increasing magnitude of the REA in dichotic listening with age in both undirected and directed recall dichotic listening conditions despite symmetrical peripheral hearing thresholds. In the oldest age group, this effect was especially striking.

Adding further support to the idea of an increased REA magnitude with aging is the electrophysiologic evidence put forward by Bellis, Nicol and Kraus (2000). The authors examined the effects of age on hemispheric asymmetry by measuring neurophysiological responses to speech stimuli. Participants were divided into three age groups (8-11 years, 20-25 years and 55 years or older). All participants had normal hearing. Peak to peak response amplitudes of the auditory cortical P1-N1 complex were obtained over the right and left temporal lobes in response to speech syllables. Findings support an age related change in the hemispheres of the brain, as seen by a more symmetrical P1-N1 evoked response in older adults compared with children and younger adults, who display a larger P1-N1 response over the left temporal lobe. The authors of this study, along with Martin and Jerger (2005) speculate that this finding may be explained by a decrease in interhemispheric function. Two prominent models of hemispheric asymmetry and aging are outlined below.

Models of Hemispheric Asymmetry and Aging

The Right Hemisphere Aging Model

It is well known that the hemispheres of the brain are anatomically and functionally asymmetric. There is also evidence that these asymmetries are affected by conditions that alter the anatomical and functional integrity of the brain, such as brain damage and aging (Dolcos et al., 2002). One model to explain these changes is the right hemisphere aging model, which proposes that the right hemisphere shows a greater and earlier age related structural and cognitive decline than the left hemisphere, affecting functions attributed to the right hemisphere to a greater degree than those associated with the left. This has been said to account for the asymmetries seen on tasks such as dichotic listening. Several behavioural studies investigating cognitive, affective and sensorimotor processing have provided mixed results in support of this model.

The first cognitive evidence of this model came from studies comparing the effects of aging on verbal and non-verbal tasks. One clear functional hemispheric asymmetry is in the processing of verbal and non-verbal information, where the left hemisphere is more involved in processing verbal information than the right. The right hemisphere has a greater role in processing non-verbal information, for example pictorial and spatial information. Goldstein and Shelly (1981) used the Wechsler Adult Intelligence Scale (WAIS) to show that elderly patients were less impaired on the verbal component (which relies on the left hemisphere) than the spatial one (which relies on the right hemisphere). The authors concluded that this indicated a greater decline in the function of the right hemisphere with aging. Elias and Kinsbourne (1974) however, found that when variables such as task complexity were controlled, there were no significant differences on verbal and spatial tasks, which does not support the idea that right hemisphere processing is selectively affected by aging.

The HAROLD Model

The HAROLD model (Cabeza, 2002) proposes that prefrontal cortex (PFC) activity during cognitive performance tends to be less lateralized in older than in younger adults, or in other words, activation becomes more symmetrical with age. Neuroimaging studies related to various aspects of memory (episodic and working memory) have provided support for this model, indicating that changes in neural architecture may occur with age. There is also some electrophysiological and behavioural evidence in support of the model.

Episodic memory refers to the encoding and retrieving of information about personally experienced past events (Cabeza, 2002). Studies have shown that during episodic memory retrieval tasks utilising verbal and non-verbal stimuli, PFC activity is lateralized in young adults on PET and functional magnetic resonance imaging (fMRI) (Cabeza & Nyberg, 2000). These activations tend to be left lateralized during encoding/semantic memory retrieval (Tulving, Kapur, Craik, Moscovitch & Houle, 1994), and right lateralized during retrieval (Nyberg, Cabeza & Tulving, 1996). This pattern is known as hemispheric encoding/retrieval asymmetry (HERA). Interestingly, findings have shown that in older adults carrying out the same tasks, there is reduced activity overall during encoding, however both the left and right PFCs are activated. This supports the idea of a reduction in asymmetry in the brain during cognitive tasks with aging (Cabeza et al., 1997). The authors interpreted this finding as compensatory, theorizing that to counteract neurocognitive deficits, older adults recruit both hemispheres to perform a task that requires one hemisphere in younger adults. This finding of bilateral activity in older adults has been replicated in a variety of episodic retrieval tasks such as word-stem cued recall, word recognition and face recognition, as well as during episodic encoding (Dolcos et al., 2000) adding more evidence to the HAROLD model as a robust general phenomenon due to a change in neural architecture.

Several studies investigating working memory have shown that PFC activity during tasks requiring verbal working memory tends to be left lateralized, whereas PFC activity during non-verbal tasks tends to be right lateralized in younger adults (Smith & Jonides, 1997). Reuter-Lorenz et al. (2000) provided clear evidence of the HAROLD model, showing that in younger adults, PFC activity during a delayed response task was significant in the left hemisphere for verbal stimuli, and significant in the right for spatial stimuli. When older adults carried out the same task, PFC activity was significant in both hemispheres during both tasks, indicating a reduction is asymmetry. Dixit, Gerton, Dohn, Meyer-Lindenberg and Berman (2000) also found evidence for the HAROLD model during an N-back task. An N-back task is a continuous performance task where the participant must indicate when the current stimulus matches one from n-steps back in the sequence. It is thought to reflect active working memory. Findings of the study indicated that in younger adults, neural activity was greater in the right PFC than the left, while in a group of middle aged adults, PFC activity was similar in the left and right PFCs on the same task. This suggests that the HAROLD pattern develops before the age of 50. Dichotic listening tasks, which are verbal in nature, would be expected to follow similar patterns of PFC activation, with greater activation over the left hemisphere in younger adults, and a smaller but more symmetrical pattern of activation in older adults. Such functional compensation at the level of the brain could explain the increasing magnitude of the REA that has been reported in adults from the age of 60 and older, as well as the decline in performance of both ears with increasing age.

Overall, age related asymmetry reductions can be found when PFC activity is right lateralized in young adults, such as in episodic memory retrieval, and when PFC activity is left lateralized in young adults during episodic memory encoding. In addition, working memory data demonstrate that age related asymmetry reductions may be found not only for process related hemispheric asymmetries (episodic retrieval vs. semantic retrieval) but also for stimuli-related hemispheric asymmetries (verbal vs. spatial working memory).

Summary of the Right Hemisphere Aging Model and the HAROLD Model

In summary, the two models reviewed provide different views of age related changes in hemispheric asymmetry. The right hemisphere aging model proposes that the right hemisphere declines at a greater rate with age than the left, whereas the HAROLD model proposes that frontal activity during cognitive performance tends to be less lateralized in older adults than in younger adults. There is mixed evidence for the right hemisphere aging model, with some studies showing that functions attributed to the right hemisphere are more affected by aging. The overall pattern is not entirely clear, and differences in methodology and task complexity may explain some inconsistencies in results. There is growing support for the idea that the age related asymmetry seen through the REA in older adults is due to the HAROLD model, which causes functional compensation at the level of the brain, rather than to general structural decline of either hemisphere (Cabeza, 2002; Dolcos et al., 2002). Ultimately, the two models are not mutually exclusive, and it is possible both are operational in different regions of the brain (Dolcos et al., 2002). It is important to bear in mind that both are still largely theoretical, and have come about in an attempt to explain the findings that are outlined above.

Working Memory and Aging

Working memory refers to a system for temporary storage and manipulation of information in the brain, necessary for complex tasks such as language comprehension and other cognitive operations (Baddeley, 1992). Working memory requires the simultaneous storage and processing of information. Hallgren et al. (2001) examined the effects of chronological age on dichotic speech tests using a range of speech stimuli. The authors aimed to determine whether dichotic listening was related to cognitive ability. The effects of attention were also examined. In the undirected attention condition, participants completed dichotic CV and digit recall tasks, and in the directed attention condition, participants completed dichotic CV, digit and sentence recall tasks. The participants were 30 hearing-impaired subjects, 15 women and 15 men, aged 42 to 84 years. Participants were divided into two subgroups (42 to 66 years and 67 to 84 years) with 15 subjects in each group. Findings revealed that test material, way of reporting, and attention all affected performance on dichotic listening. There was a reduced performance in all dichotic speech tests overall in the older group and a reduction in left ear performance on the directed attention task with increasing age. Reaction time was also slower for the older the older group. The authors hypothesized that although peripheral hearing sensitivity may have had some role to play in the overall decline in performance, it did not account for all differences seen between older and younger participants. It is therefore likely to be due to a combination of reduced central processing, and age related changes in cognitive function.

Sex-related Differences in Dichotic Listening

As a general rule, there are no clear differences between men and women in dichotic listening, however Bellis and Wilber (2001) have reported clinical observations of a stronger REA in men aged between 40 and 50 years on an undirected dichotic digit test. The authors reported that in their clinical experience, they have seen an increased proportion of middle aged men referred for central auditory processing assessment due to difficulties hearing in noise. The methodology and scoring used by Bellis and Wilber is described above, however it is worth nothing that the authors divided participants into four age groups (20-25, 35-40, 55-60 and 70-75). These groups were selected to control for the effects of menopause, with two groups pre-menopause and two groups post-menopause. Results showed a decrease in the interhemispheric transfer of information and an increase in the size of the REA for males aged 35-40 years compared to females, who demonstrated preserved function until the post menopausal years. After the age of 55, there was no significant difference in the magnitude of the REA between males and females, however there was a continued decline in both right and left ear dichotic performance, with a decrease in left ear performance being more marked than the right ear. This finding is consistent with an increase in the REA with increasing age.

Jerger et al. (1994) also found that males showed a larger REA on both undirected and directed attention tasks using dichotic sentence stimuli. Data for 44 males and 34 females aged 50-91 were examined, and a mean ear difference score on the dichotic sentence test was calculated for both directed and undirected conditions. Results showed that the difference between mean ear scores was smaller in females than males, with an average 30% difference between the left and right ears in males, compared with a 10% difference between ears in females. The differences reported were not statistically significant. The authors speculated that the phenomenon of a larger REA in males can be explained by a structural or auditory component rather than a task related or cognitive component which supports the bottom-up processing model. It is worth nothing that the authors did not match groups by sex, despite the fact that the study was investigating differences between males and females. Further, there was no explicit control of handedness, and a lax criterion relating to interaural asymmetry was adopted. Similarly, the large age range in the study meant the authors had problems with ceiling effects, however the results attempted to account for all three of these factors and given that it was a retrospective study, there was little chance of controlling these factors at the outset.

More recently, Hirnstein et al. (in press) utilized the large Bergen dichotic listening database to examine whether true sex effects in dichotic listening existed. The Bergen database contains information from several experiments and laboratories that have employed the same dichotic listening paradigm using standardized instructions and CV stimuli. Hirnstein et al. examined findings for 1782 participants (897 males & 885 females) in four age groups (children <10 years, adolescents 10-15 years, younger adults 16-49 years and older adults >50 years), and found no overall sex difference in dichotic listening. The authors did find a significant interaction between age and sex, with language lateralization sometimes larger in males and sometimes larger in females, depending on age. Specifically, there was an earlier onset REA in females, with a stronger magnitude in female compared with male adolescents. Also, younger male adults showed a greater REA than younger female adults. There were no sex differences in children and older adults. Taken together, the findings of this large study seem to indicate that sex differences in language lateralization via dichotic listening exist, but they are age dependent and relatively small.

Summary of Dichotic Listening, Aging and Sex

It appears that there is an increased magnitude in the REA for processing linguistic information by age and possibly sex (Hirnstein et al., in press). This effect has been evident in directed and undirected listening tasks (Jerger et al., 1994). Most research indicates that increasing asymmetry seen on dichotic listening tests with age, as evidenced by a pronounced REA, is likely due partly to a decline in cognition (especially memory and information processing strategies), partly due to the effects of aging on the auditory structures and pathways, and partly to a reduction in hemispheric transfer of information via the corpus callosum (Jerger et al., 1994). Findings related to sex effects are far less conclusive and have not been fully explored, but seem to be dependent on developmental stage (Jerger et al., 1994; Bellis & Wilber 2001). No sound theoretical basis has been put forward to serve as a plausible explanation to date, however links have been made to sex-related changes to the structure of the corpus callosum (Suganthy et al., 2003) and the effect of menopause in women (Bellis & Wilber, 2001). Therefore, the present study aimed to partially replicate the findings of Hirnstein et al. in an attempt to determine whether age and/or sex effects in dichotic listening are truly a robust phenomenon.

Statement of the Problem

Dichotic listening is a means of assessing brain lateralisation with the structural (bottom-up processing) and attentional models (top-down processing) indicating two different ways of processing auditory information. Bottom-up processing is seen when the signal presented to the cochlea reaches the auditory cortex with strong evidence of a REA. This is due to the direct pathway from the right cochlea to the language centres in the contralateral left hemisphere of the brain. Top-down processing occurs when attention is deliberately directed to a particular ear, and this can increase or decrease the REA. The enhancement of the REA occurs because the left hemisphere is primed for speech stimuli. Attempts to examine bottom-up and top-down features of dichotic listening have been made by directed and undirected listening. These studies have shown that the strength of the REA can be successfully manipulated.

Interestingly, past research has shown that in both directed and undirected attention tasks, the magnitude of the REA becomes more pronounced with aging. Further, this effect tends to be seen at different times in the age span of males than females (Jerger et al., 1994; Bellis & Wilber, 2001), although this difference is less apparent in children and adults beyond 50 years of age (Hirnstein et al., in press). As this finding has not been adequately explained to date, this study seeks to further explore the effects of age and sex on dichotic listening. It is important to recognize that past studies noting age and sex-related differences in performance have used dichotic stimuli consisting of sentences and multiple digits. Such stimuli are likely to have adverse effects on cognition and memory in the older population. Ideally, employing a methodology utilising CV stimuli could reduce these effects. Further, the effects of altering the IID on age and sex-linked dichotic listening performance have not been thoroughly examined. A methodology manipulating the IID would allow for a critical look at hemispheric participation in the transfer of information through a dichotic listening task. This would show whether these changes in intensity facilitate listening in the elderly, which has implications for the fitting of amplification in this population. The purpose of this study was to further investigate age- and sex-related changes in dichotic listening by using CV stimuli and altering the IID. The following null hypotheses were proposed:

Undirected Attention:

1. *There will be no significant difference between younger and older adults in the magnitude of the REA at equal intraaural intensity.*
2. *There will be no significant difference in the REA magnitude between males and females as a function of increasing age at equal intraaural intensity.*
3. *There will be no significant difference between younger and older adults in the REA magnitude when the IID is altered.*
4. *There will be no significant difference between males and females as a function of increasing age in REA magnitude when IID is altered.*

Directed Attention:

5. *There will be no significant difference between younger and older adults in the magnitude of the REA at equal intraaural intensity.*
6. *There will be no significant difference between males and females as a function of increasing age in the magnitude of the REA at equal intraaural intensity.*

To test these null hypotheses, the following research questions were developed:

1. *Do older adults show a greater magnitude in the REA than younger in an undirected attention dichotic listening task at equal intraaural intensity?*

2. *Do males show a greater magnitude in the REA than females, and does this change as a function of age in an undirected attention dichotic listening task at equal intraaural intensity?*
3. *Do older adults show a greater magnitude in the REA than younger adults in an undirected attention dichotic listening task when the IID is altered?*
4. *Do males show a greater magnitude in the REA than females, and does this change as a function of age in an undirected attention dichotic listening task where the IID is altered?*
5. *Do older adults show a greater magnitude in the REA than younger adults in a directed attention dichotic listening task?*
6. *Do males show a greater magnitude in the REA than females and does this change as a function of age in a directed attention dichotic listening task?*

Method

Participants

A total of 40 healthy, right-handed adults took part in the study. There were 10 participants (5 men, 5 women) within four age groups: 35-44 years (group 1), 45-54 years (group 2), 55-64 years (group 3), and 65-74 years (group four). Participants were recruited from within the University of Canterbury community as well as through personal acquaintances and word of mouth. The general characteristics of each group can be found in Table 1. The age ranges were chosen to represent discrete points in time in the adult life span. Each participants hearing was screened at octave frequencies between 500 and 4000 Hz. Only participants with normal hearing or bilateral, symmetrical sensorineural hearing loss were included in the study. Bone conduction testing was undertaken when air conduction thresholds at any of these frequencies were greater than 20 dBHL. Those participants with an air-bone gap greater than 15dB at any of these frequencies were excluded from the study. One participant was excluded on the basis of this criterion and follow-up care was arranged. Interaural asymmetry was quantified by comparing the pure tone average from 500 to 4000 Hz between ears. Participants with a difference of 10dBHL or more between the left and right ears were excluded from the study (Bellis & Wilber, 2001). One participant was excluded on the basis of this criterion and follow-up care was arranged.

Handedness for each participant was obtained according to the Edinburgh Handedness Inventory (Oldfield, 1971) because the location of the language-dominant hemisphere can be more commonly found on the right side in left-handed individuals (Knecht et al., 2000). The resultant laterality quotient derived from the inventory indicated that all participants were right-handed. A copy of the Edinburgh Handedness Inventory Questionnaire can be found in Appendix I.

None of the participants reported a history of neurological disease or mental illness. A screen of cognition was also undertaken for each participant using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The MoCA is a screening test used to detect mild cognitive impairment. In the present study it was used to establish cognitive function and memory for each participant before completing the dichotic listening task. A copy of the MoCA and scoring instructions are included in Appendix II. All participants scored at or above the cut-off level of 26 points. Ethical approval was obtained by the University of Canterbury Human Ethics Committee prior to commencement of data collection, which can be found in Appendix III. Participation was voluntary and participants gave written informed consent. A copy of the information sheet and consent form can be found in Appendix IV.

Table 1. General characteristics of participants. The table includes sex, age, group, handedness, cognitive score, pure tone average (PTA), and other audiological factors.

Participant	Sex	Age (years)	Age group (years)	Handedness*	Cognition (out of 30)**	PTA(dBHL) R	L	Other audiological factors
1	M	39	35-44	100%	29	10	10	
2	M	40	35-44	100%	26	15	20	Headphones due to exostoses + ear drum perforation
3	M	39	35-44	83%	27	10	15	
4	M	35	35-44	100%	28	15	10	Headphones due to wax
5	M	43	35-44	83%	26	10	10	
6	F	43	35-44	83%	29	10	5	Headphones due to wax
7	F	39	35-44	83%	29	20	15	
8	F	37	35-44	100%	30	10	10	
9	F	39	35-44	100%	30	0	5	
10	F	37	35-44	83%	30	5	10	
11	M	54	45-54	83%	30	15	10	
12	M	51	45-54	60%	28	20	20	
13	M	52	45-54	100%	28	15	15	

14	M	45	45-54	64%	30	5	10	
15	M	50	45-54	83%	27	15	20	
16	F	54	45-54	100%	29	10	10	
17	F	52	45-54	67%	30	10	10	
18	F	54	45-54	100%	30	10	10	
19	F	53	45-54	83%	30	15	20	
20	F	53	45-54	100%	27	15	15	
21	M	56	55-64	100%	27	10	5	
22	M	58	55-64	83%	27	15	20	
23	M	64	55-64	83%	27	10	10	Headphones due to wax
24	M	57	55-64	83%	27	15	20	
25	M	63	55-64	100%	27	15	20	
26	F	55	55-64	100%	26	10	10	
27	F	59	55-64	100%	28	5	10	
28	F	56	55-64	100%	28	10	5	
29	F	64	55-64	100%	28	10	10	
30	F	61	55-64	100%	29	15	15	
31	M	69	65-74	100%	26	15	15	
32	M	68	65-74	83%	28	25	20	
33	M	67	65-74	83%	30	30	30	

34	M	67	65-74	100%	28	10	15	Headphones due to wax
35	M	65	65-74	100%	28	45	40	Has hearing aids; rarely wears
36	F	65	65-74	83%	28	20	25	
37	F	65	65-74	100%	27	15	15	
38	F	67	65-74	90%	29	10	10	
39	F	73	65-74	100%	27	15	20	
40	F	66	65-74	100%	28	20	15	

*All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

**All participants had cognitive scores within the normal range according to the MoCA (Nasreddine et al., 2005).

Materials and Stimuli

A calibrated audiometer (Grason-Stadler Inc. 60), using insert earphones (EAR-3A) or supra-aural headphones (TDH-39), and pure tone stimuli were used to conduct the hearing screens. The dichotic listening stimuli consisted of six CV syllables, including three syllables with voiced stop consonants (/ba/, /da/ and /ga/), and three syllables with unvoiced stop consonants (/pa/, /ta/ and /ka/). A recording of the CV tokens was made using an adult male speaker of New Zealand English. Adult male speakers have been used in past dichotic listening studies manipulating the IID (Tallus et al., 2007).

Dichotic stimuli were presented through headphones (Sennheiser HD215), driven by a sound card (InSync Buddy USB 6G) attached to a laptop computer (E-machines). For calibration, the headphones were placed on a Head and Torso Simulator (HATS) (Brüel & Kjær Type 4128) connected to an Input/Output Controller Module (Brüel & Kjær 7539 5/1-ch.). The 1-second average A-weighted sound level of each syllable sample was measured using a noise and vibration analysis platform (Brüel & Kjær PULSE 11.1). This information was used to adjust the level of each syllable to ensure presentation at 70 dB (A) during subsequent testing.

A specially designed software programme was used to present the CV syllables, analyse the responses and display the subsequent results. The syllables were normalized for intensity and were paired to create all six possible combinations of the three voiced CVs and the six possible combinations of the three unvoiced CVs (e.g., /ba/-/da/ or /pa/-/ta/). The pseudo-randomization for the IID task was done via a specially designed software programme, which used four rules to eliminate learning and order effects, and which followed past research (Hugdahl et al., 2008a). The presentation order was psuedorandomised within and between blocks by applying each of the following restrictions: (1) not more than two consecutive trials with the same intensity difference condition, (2) not more than two trials in a row with the same direction of intensity change, (3) no presentations of the same syllable to the same ear in consecutive trials and (4) no repetition of a syllable pair in two consecutive trials. The randomization for the directed attention task was achieved using the same programme. Attention was randomly directed to each ear with no more than two consecutive presentations to the same ear. There was the same number of trials with attention directed to each ear. The ear the participants started with was again randomized.

Procedure

Each participant was given an information sheet and consent form regarding the study purpose and procedures. They were provided with a chance to ask questions before being asked to sign the informed consent form. The Edinburgh Handedness Inventory (Oldfield, 1971) and the MoCA (Nasreddine at al., 2005) were administered in a quiet room, and the hearing screen took place in a sound treated room at the University of Canterbury Speech and Hearing Clinic. Instructions were provided on the dichotic listening task. The undirected attention task was always carried out first by all participants, followed by the directed attention task. Completing the directed task first may have had an adverse effect on results, by priming the participants for their performance on the undirected task.

The dichotic listening tasks were controlled using a laptop computer (E-machines). Each participant was seated in front of the laptop in a comfortable position, and given verbal instructions prior to commencing the task. The instructions were as follows:

> *"Now you will be completing some listening tasks. I will go through the instructions at the beginning of each task and you will also have the instructions displayed on the screen in front of you. All tasks should take approximately 40 minutes to complete."*

Undirected Attention Dichotic Listening Task

In preparation for the undirected task, participants were required to first complete a perceptual calibration listening task. The task was designed to establish the interaural intensity balance for each individual, in order to account for any audiometric asymmetries of individual participants. Participants were fitted with the headphones while facing the laptop computer. Each CV stimuli was presented to the participants simultaneously via the headphones and repeated continuously at two second intervals. The participant was required to move a linear slide bar to a location where the CV was heard equally in both ears. This was completed for each of the six CVs (/ba/, /da/, /ga/, /pa/, /ta/, /ka/). The median score of the slider position was used as the interaural intensity balance for that participant. The display screen seen by participants for one of the CV stimuli for the perceptual calibration task is shown in Figure 3. The verbal instructions for the perceptual calibration task were as follows:

> *"You will hear sounds like /ba/ or /ga/ repeating in both of your ears. You need to listen to these repeating speech sounds and move the slider to a place where the sounds appear to be coming from both ears equally. You can use the mouse or the left and right arrow key to do this. The sounds should feel like they are in the centre of your head. The slider may not necessarily be in the centre for each sound. Click 'continue' when you have finished with each speech sound, there are six in total. I will then give you the instructions for the next task."*

Once the interaural intensity balance was complete, participants commenced the undirected dichotic listening task. During this task, the IID was randomly varied for each ear. Each participant was given verbal instructions before commencing the task, during which time they were also told that the instructions would also be displayed on the screen. The on-screen instructions and the display screen after listening to each presentation is shown in Figure 4. The verbal instructions given to participants are as follows:

> *"You will hear different speech sounds played into both ears at the same time. You need to select from the screen which sound you heard by clicking with the mouse. Alternatively you can use the up arrow key for the top sound option and the down arrow key for the bottom sound option. If you hear both speech sounds, please indicate which you heard more clearly. There will be breaks in this task, where you can select to have a break or to continue. It may be easier to close your eyes while listening to each presentation. The instructions for this task are displayed on the screen in front of you. Once you have read these, click 'continue' and the first presentation will start immediately. This task will take approximately 20 minutes."*

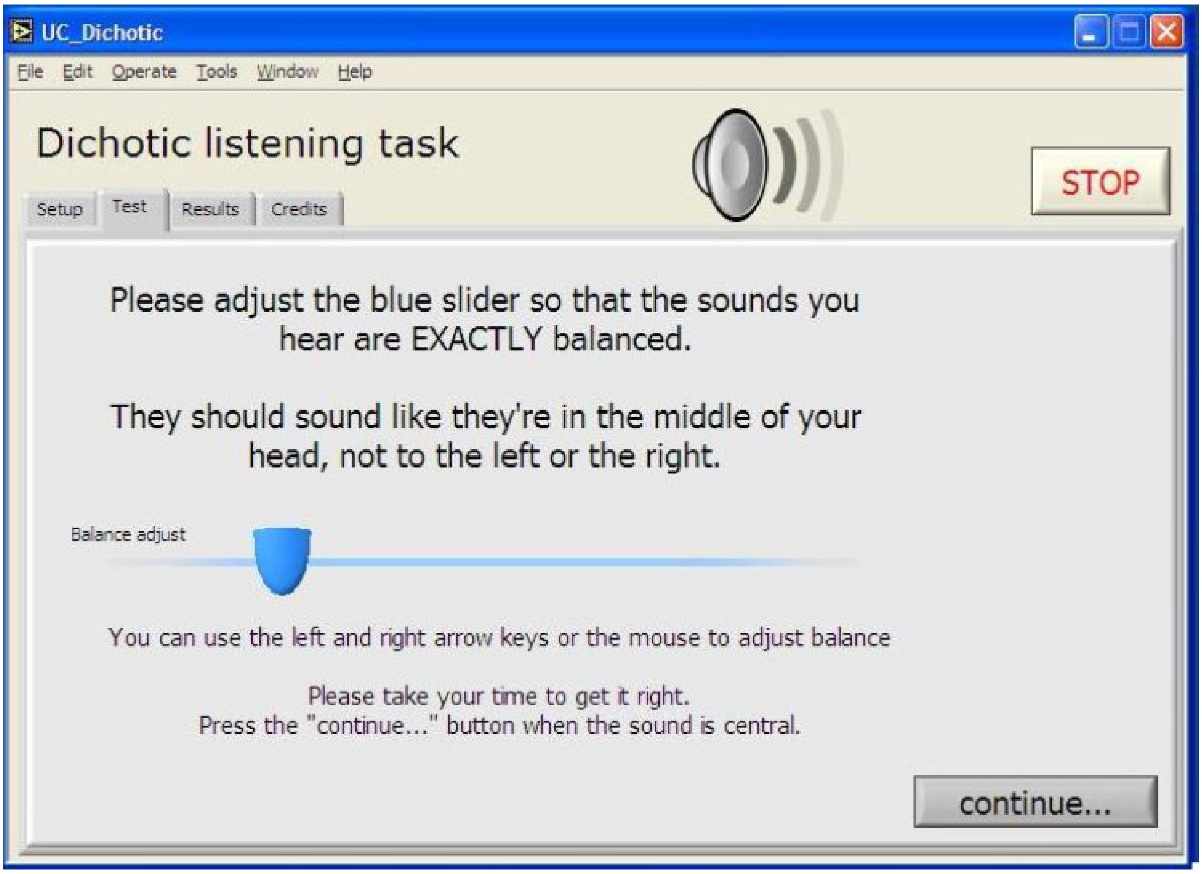

Figure 3. Screenshot of the perceptual calibration task, where participants were to move the slider to a position where the speech sounds sound exactly balanced in both ears i.e., in the centre of their head. This is the screen that appeared for each of the six CV syllables.

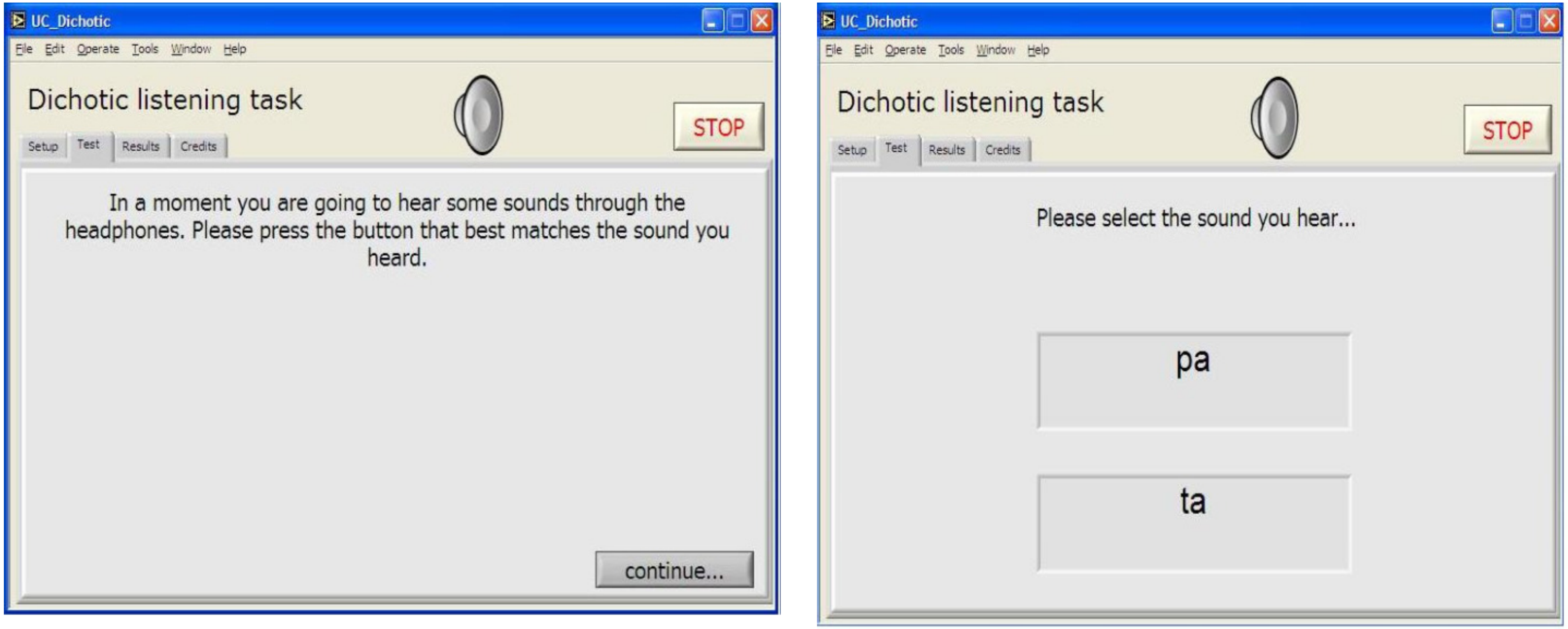

Figure 4. A screenshot for the undirected listening task, where participants were instructed to select the sound they heard (left panel). A screenshot showing an example of the display screen for one of the speech sound combinations (right panel).

Directed Attention Dichotic Listening Task

Prior to completing the directed attention task, a perceptual calibration task, identical to the one described earlier, was undertaken. The calibration was designed to ensure there were no perceptual interaural differences for the CV stimuli for each participant. Once the CV intensity levels were calibrated the directed attention task commenced. This task involved the participants deliberately placing their attention towards either their right or left ear and reporting what they heard. Each participant was given verbal instructions and told the instructions would also be displayed on the screen. The on-screen instructions are displayed in Figure 5. After listening to each presentation of the paired stimuli, participants were required to select what they heard in the ear they were instructed to attend to, as indicated by a blue arrow. Examples of the screenshots showing the right and left attention conditions are displayed in Figure 6. There was no alteration in IID in the directed attention condition, with stimuli presented at equal loudness binaurally. The verbal instructions given to participants were as follows:

> *"You will again hear different speech sounds played into both ears at the same time. In this task you need to focus your attention to either the left or right ear and then select the speech sound you hear in that ear by clicking it with the mouse. Alternatively, you can use the up arrow key for the top sound option, or the down arrow key for the bottom sound option as before. When you need to listen to what is played in your left ear, an arrow will point to the left side of the screen. When you need to listen to what is played in your right ear, an arrow will point to the right side of the screen. Again there will be breaks in this task, where you can select to have a break or to continue. The instructions for this task are also displayed on the screen in front of you. Once you have read these, click 'continue' and the first presentation will start immediately. This task will take approximately 20 minutes."*

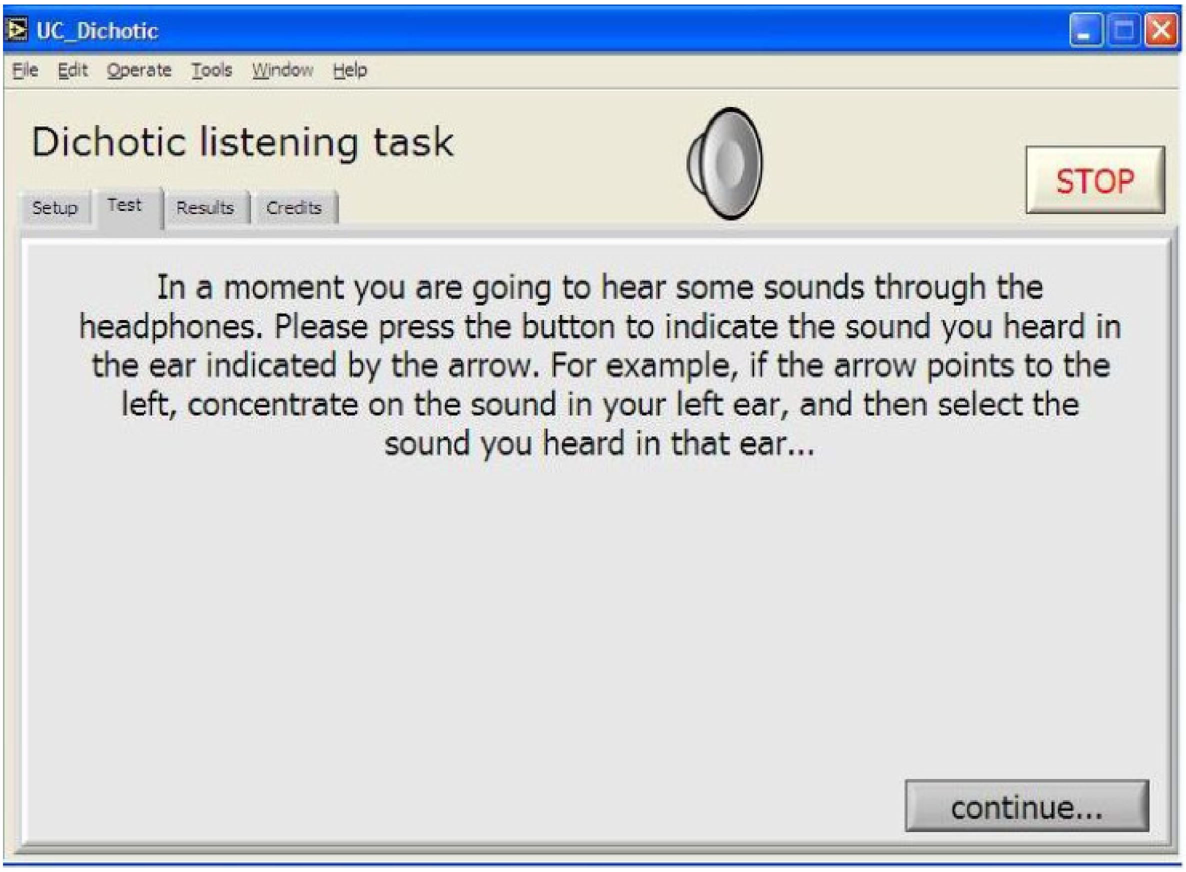

Figure 5. Screenshot of instructions for the directed listening task, where participants were instructed to focus their attention toward the ear indicated by an arrow.

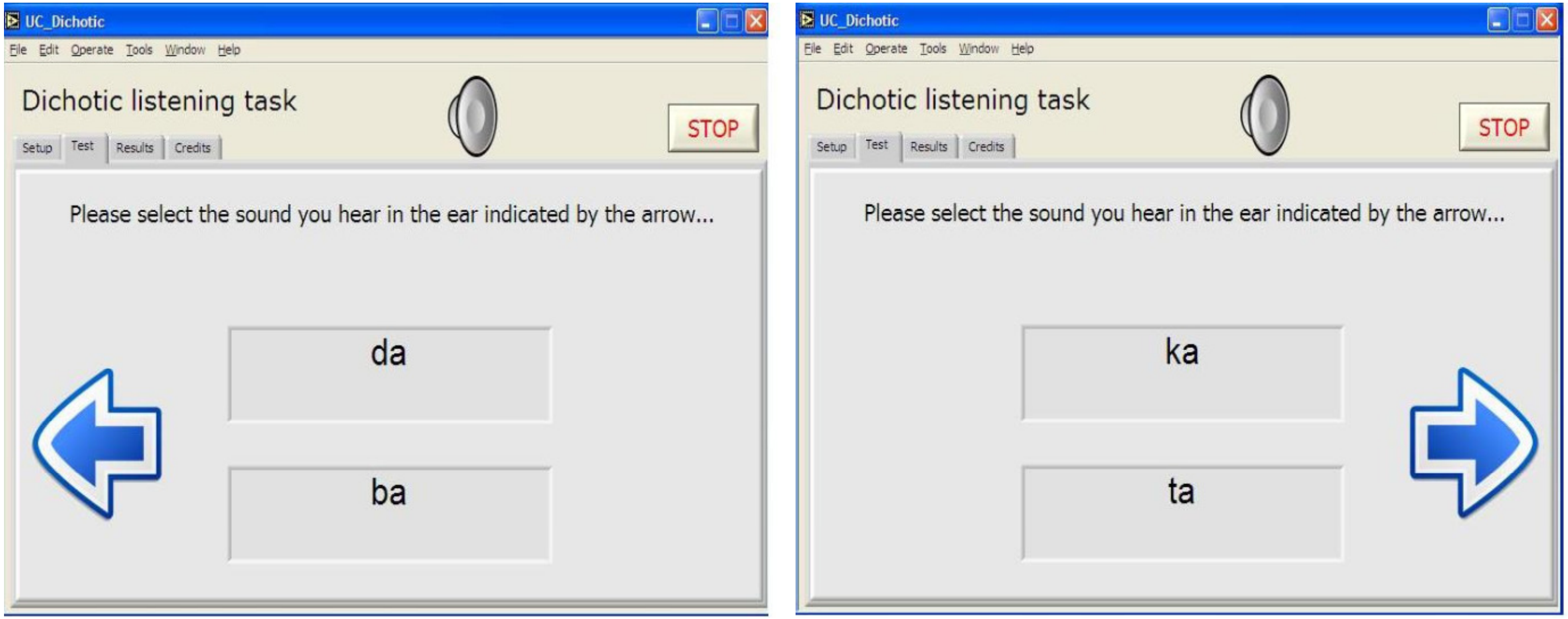

Figure 6. The screenshot for the directed attention task, where the options of speech sounds are shown after presentation and the participants are required to select the sound they hear in the attended ear. An example of the screenshot for the directed-left attention task is shown in the left panel and an example of the screenshot for the directed-right task is shown in the right panel.

Data Analysis

Group means for each presentation type (undirected & directed attention tasks) were obtained for each age group, each sex, and each age group according to sex. For the undirected attention paradigm, the magnitude of these differences was compared in two ways. The first was the percentage of correct responses for the right ear at 0 dB IID. The second factor examined was the cross-over level (dB) at which the REA became a LEA. This cross-over level was estimated by first order polynomial (linear regression) on to right and left ear IID data plots. The point at which these data plots intersected was taken as the cross-over level. The IID was varied using a range of -21 dB to 21 dB, where -3 to -21 dB indicated greater intensity in the left ear, 0 dB being equal intensity levels in both ears, and 3 to 21 dB indicated greater intensity in the right ear.

A series of analyses of variance (ANOVAs) were run to evaluate performance on the undirected attention dichotic listening task, according to age (younger and older adults), sex (males and females) and age by sex interaction (males and females in different age groups). The within group factor was age, and the between group factor was sex. For the directed attention condition, ANOVAs were run to evaluate differences in the directed-right and directed-left conditions. The average number of correct responses at 0 dB IID for the ear attention was directed to (right or left) were obtained. Variables examined included age, sex and age by sex. Statistically significant results were followed up with post-hoc analyses.

Results

The results are presented in two sections. The first section contains the results for the undirected attention task and the second section contains the results for the directed attention task.

Undirected Attention Task: Age

The individual results of the undirected attention task for each of the age groups are provided in Appendix V to Appendix XII.

Group 1 (35-44 years): The combined results for the 35-44 year-old group are shown in Figure 7a. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -9 dB, indicating that the REA persisted until the CV in the left ear was 9 dB more intense than the right ear. A first-order polynomial (linear regression) was fit to the right ear and left ear IID data points respectively to estimate the level at which the REA became a LEA. The point at which these data plots intersected was taken as the “cross-over” level. The cross-over level for the two polynomials in this group was calculated to be -5 dB. The right ear was selected an average of 57% of the time when the IID was 0dB.

Group 2 (45-54 years): The combined results for the 45-54 year-old group are shown in Figure 7b, and show that the largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level was -8 dB. The right ear was selected 68% of the time when the IID was 0dB on average.

Group 3 (55-64 years): Figure 7c displays the combined results for the 55-64 year-old group. This largest REA was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -9 dB. The average cross-over level was calculated at -6 dB, and the right ear was selected an average of 65% of the time when the IID was 0dB.

Group 4 (65-74 years): As shown in Figure 7d, the largest REA for the 65-74 year-old group was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -9 dB, indicating that the REA persisted until the CV in the left ear was 9 dB more intense than the right ear. The average cross-over level was calculated to be -6 dB. On average, when the IID was 0 dB the right ear was selected 61% of the time.

To evaluate whether dichotic listening performance differed as a function of age, two separate ANOVA tests were performed. The first test was based on the percentage of times the right ear stimulus was chosen when the IID was 0dB. The test was not significant [$F(3, 32) = 1.779$, $p = 0.171$, $\eta_p^2 = 0.143$] [1], indicating no age differences in dichotic listening performance when the stimuli were equally loud in both ears. The overall REA average for all four groups was 63% at 0 dB IID. The second ANOVA was based on the cross-over level in dB where the REA became a LEA. The resulting ANOVA across age groups was not significant [$F(3, 32) = 0.589$, $p = 0.627$, $\eta_p^2 = 0.052$], indicating no age differences in dichotic listening performance in terms of the level at which the REA became a LEA. The overall average cross-over level for all four groups was -6 dB.

[1] The partial eta statistic (η_p^2) provides as estimate of overall effect size. The value can range from 0 (no effect) to 1 (large effect).

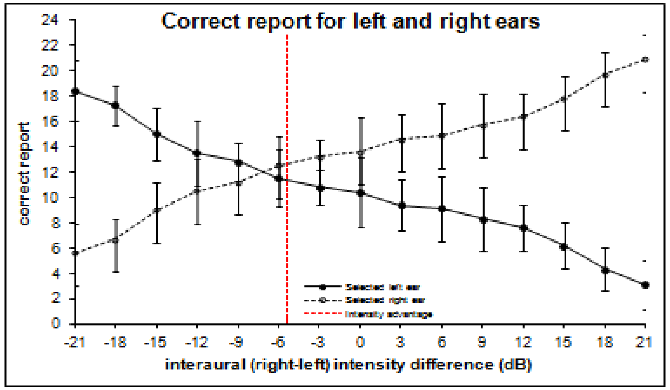

Figure 7a. Participants aged 35- 44

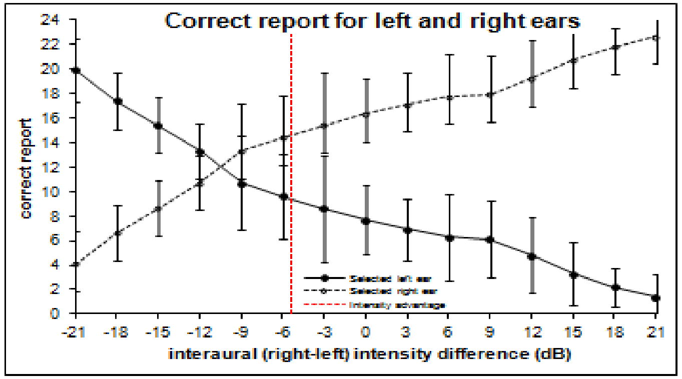

Figure 7b. Participants aged 45-54

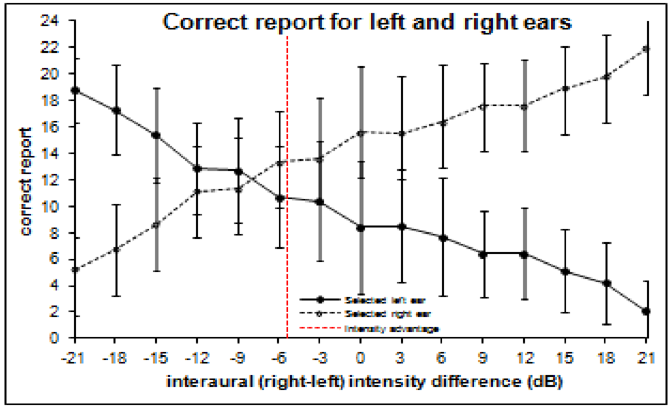

Figure 7c. Participants aged 55-64

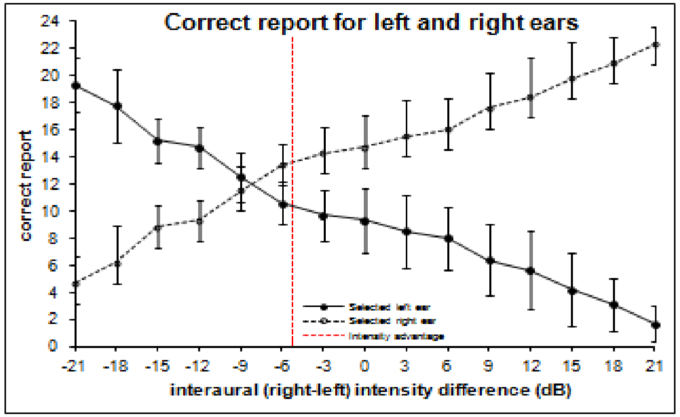

Figure 7d. Participants aged 65-74

Figure 7 a, b, c, d. Correct report for all participants collapsed across sex for left and right ear CV stimuli as a function of changing the interaural intensity difference (IID) (dB). An IID of -3 to -21 indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears, and 3 to 21 dB indicates greater intensity in the right ear.

Undirected Attention Task: Sex

The individual results of the undirected attention task for males and females are shown in Appendix V to Appendix XII.

Females: The combined results for the females are shown in Figure 8a. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -9 dB, indicating that the REA persisted until the CV in the left ear was 9 dB more intense than the right ear. The average cross-over level from a REA to a LEA was -7 dB. The right ear was selected 65% of the time on average when the IID was 0dB.

Males: The combined results for the males are shown in Figure 8b. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level from a REA to a LEA was calculated to be -6 dB, and on average, the right ear was selected 60% of the time when the IID was 0dB.

To evaluate whether dichotic listening performance differed as a function of sex, two separate ANOVA tests were performed. The first test was based on the percentage of times the right ear stimulus was chosen when the IID was 0dB. The test was not significant [$F(1, 32) = 1.880$, $p= 0.180$, $\eta_p^2=0.055$], indicating no sex differences in undirected dichotic listening performance when the stimuli were equally loud in both ears. The second ANOVA was based on the cross-over level in dB where the REA became a LEA. The resulting ANOVA across sexes was not significant [$F(1, 32) = 0.183$, $p= 0.672$, $\eta_p^2=0.006$], indicating that there was no difference between males and females in undirected listening performance, in terms of the level the REA became a LEA.

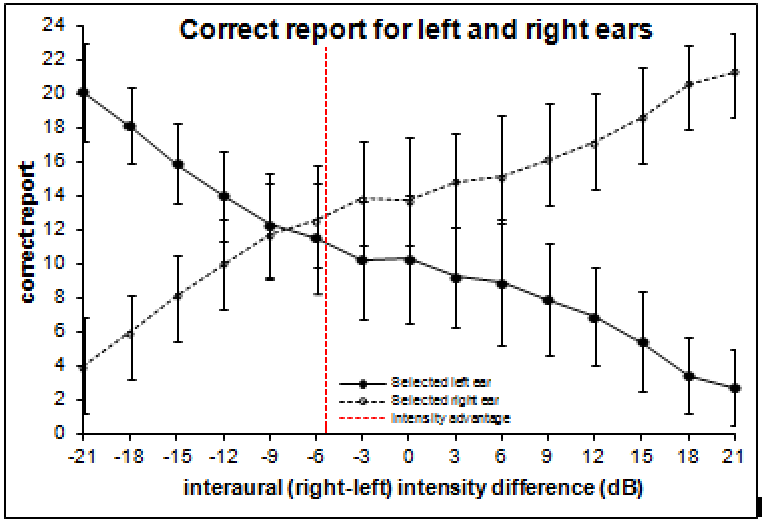

Figure 8a. Females aged 35-74

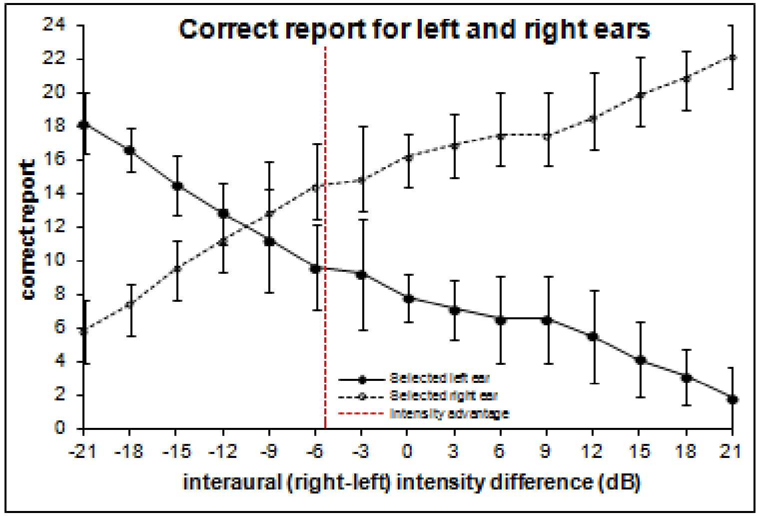

Figure 8b. Males aged 35-74

Figure 8 a, b. Correct report for females and males collapsed across all four age groups (35-74 years) for left and right ear CV stimuli as a function of changing the IID (dB). An IID of -3 to -21 indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears, and 3 to 21 dB indicates greater intensity in the right ear.

Undirected Attention Task: Age and Sex

The individual results of the undirected attention task for males and females in all four age groups are shown in Appendix V to Appendix XII.

Females:

Group 1(35-44 years): The combined results for the females aged 35-44 are shown in Figure 9a. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -3 dB. A reversal of the REA to a LEA was found at the IID of 0 dB. The average cross-over level from a REA to a LEA was calculated to be -2 dB. On average, the right ear was selected 48% of the time when the IID was 0dB.

Group 2(45-54 years): Figure 9b shows that for females aged 45-54, the largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level from a REA to a LEA worked out to be -6 dB. The right ear was selected 66% of the time when the IID was 0dB on average.

Group 3(55-64 years): The combined results for the females aged 55-64 are shown in Figure 9c. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -9dB and -12dB. A reversal of the REA to a LEA was found at the IID of -15 dB. The average cross-over level from a REA to a LEA was calculated to be -11 dB. The right ear was selected 78% of the time on average when the IID was 0dB.

Group 4(65-74 years): Figure 9d shows that for females aged 65-74, the largest REA was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level from a REA to a

LEA was -7 dB, and on average, the right ear was selected 68% of the time when the IID was 0dB.

Two ANOVAs were performed to evaluate whether dichotic listening performance differed in females as a function of increasing age. The first ANOVA was based on performance at an IID of 0 dB. The test was significant ($p<0.05$). Follow-up pairwise comparisons identified that females in group one (35-44 years) displayed a significantly smaller REA magnitude than females in group two (45-54 years) [$p=0.22$], group three (55-64 years) [$p=0.000$] and group four (65-74 years) [$p=0.010$] (Figure 11). The second ANOVA was based on the cross-over level in dB at which the REA became a LEA. This test was significant ($p<0.05$). Follow-up pairwise comparisons revealed that females in group one (35-44 years) displayed a significantly lower cross-over level from REA to LEA than females in group three (55-64 years) [$p=0.014$]. This indicates that in younger females, the REA becomes a LEA at a significantly lower intensity level than slightly older females (Figure 12).

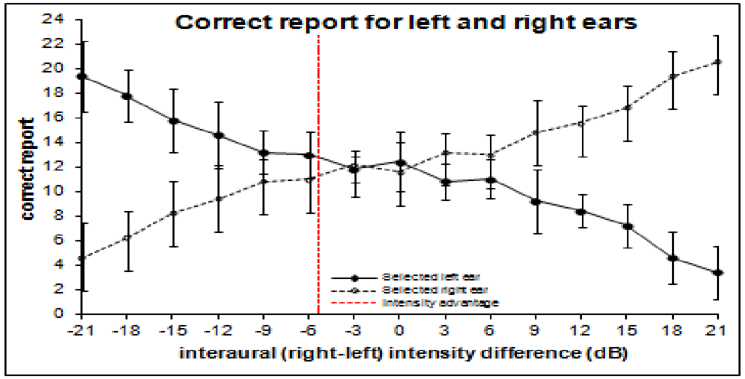

Figure 9a. Females aged 35-44

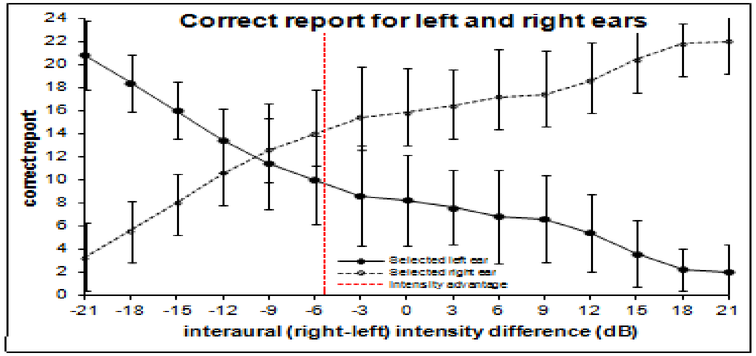

Figure 9b. Females aged 45-54

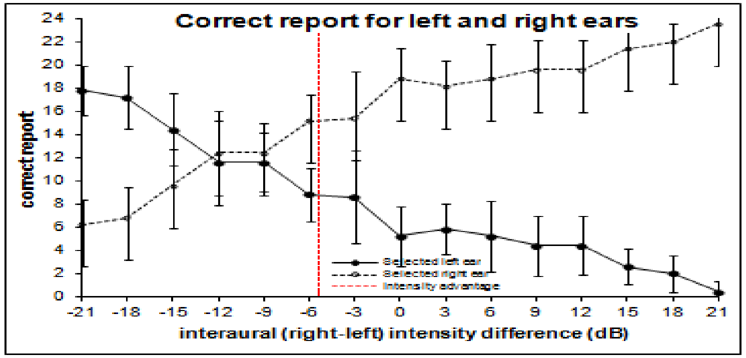

Figure 9c. Females aged 55-64

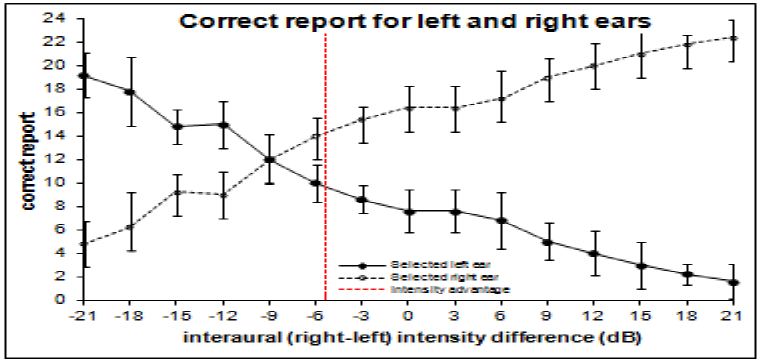

Figure 9d. Females aged 65-74

Figure 9 a, b, c, d. Correct report for females aged 35-74 for left and right ear CV stimuli as a function of changing the IID (dB). An IID of -3 to -21 indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears, and 3 to 21 dB indicates greater intensity in the right ear.

Males:

Group 1(35-44 years): The combined results for the males aged 35-44 are shown in Figure 10a. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at -6 dB. A reversal of the REA to a LEA was found at the IID of -9 dB. The average cross-over level from a REA to a LEA was -8 dB. On average, the right ear was selected 65% of the time when the IID was 0dB.

Group 2(45-54 years): Figure 10b shows that for males aged 45-54, the largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level from a REA to a LEA was calculated to be -9 dB. The right ear was selected 70% of the time on average, when the IID was 0dB.

Group 3(55-64 years): The combined results for the males aged 55-64 are shown in Figure 10c. This figure shows that the largest REA was found at the IID of 21 dB and the smallest REA was found at 0 dB. A reversal of the REA to a LEA was found at the IID of -3 dB. The average cross-over level from a REA to a LEA was calculated to be -2 dB, and on average, the right ear was selected 52% of the time when the IID was 0dB.

Group 4(65-74 years): Figure 10d shows that for males aged 65-74, the largest REA was found at the IID of 21 dB and the smallest REA was found at -9 dB. A reversal of the REA to a LEA was found at the IID of -12 dB. The average cross-over level from a REA to a LEA was -4 dB. On average, the right ear was selected 54% of the time when the IID was 0dB.

ANOVA testing was performed to evaluate whether dichotic listening performance differed in males as a function of increasing age. The first ANOVA (based on performance at an IID of 0 dB) revealed a significant difference ($p<0.05$). Pairwise comparisons revealed that males in group two (45-54 years) displayed a significantly higher REA magnitude than males in group three (55-64 years) [$p=0.017$] or group four (65-74 years) [$p=0.038$] (Figure 11). The second ANOVA (based on the cross-over level from a REA to a LEA in dB) was also significant for males as a function of age ($p<0.05$). Follow-up post-hoc tests indicated that males in group three (55-64 years) had a significantly lower cross-over point than males in group two (45-54 years) [$p=0.036$]. This indicates that in males aged 55-64 the REA becomes a LEA at a significantly lower intensity level than males aged 45-54 (Figure 12).

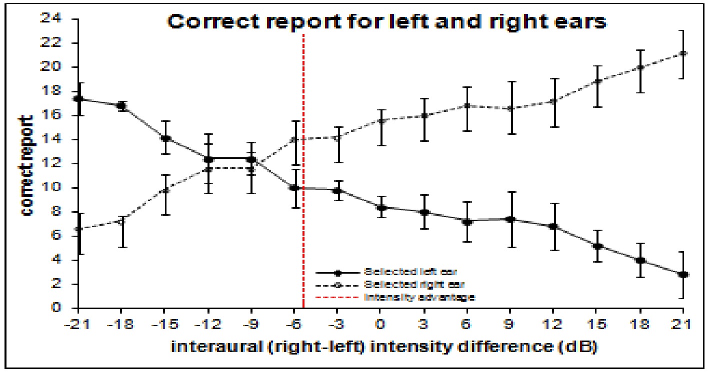

Figure 10a. Males aged 35-44

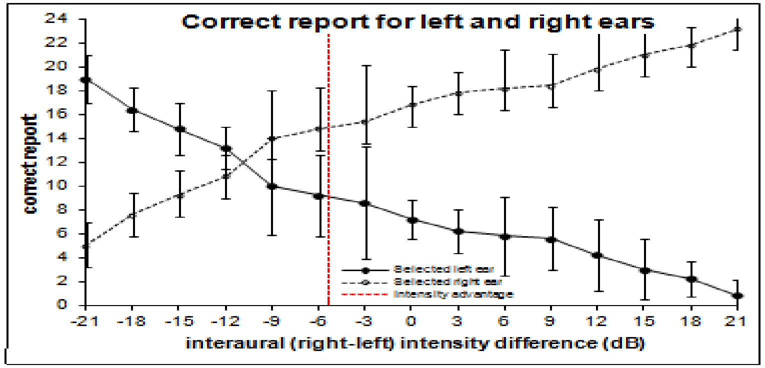

Figure 10b. Males aged 45-54

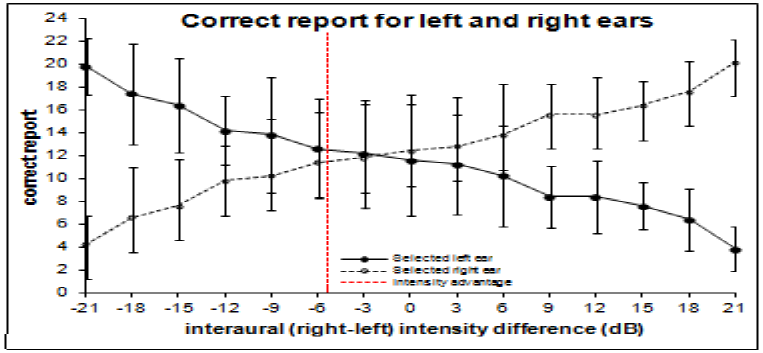

Figure 10c. Males aged 55-64

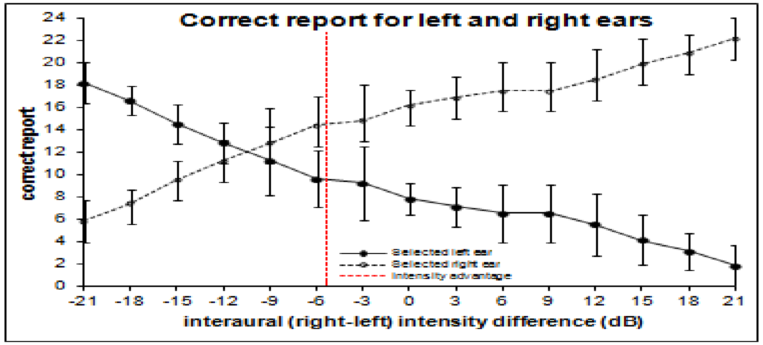

Figure 10d. Males aged 65-74

Figure 10 a, b, c, d. Correct report for males aged 35-74 for left and right ear CV stimuli as a function of changing the IID (dB). An IID of -3 to -21 indicates greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ears, and 3 to 21 dB indicates greater intensity in the right ear.

Males and females in all age groups

To evaluate whether dichotic listening performance differed as a function of age and sex, two separate two-way ANOVA tests were performed. The first ANOVA was based on the percentage of times the right ear stimulus was chosen when the IID was 0dB. The within group factor was age and the between group factor was sex. The test was significant [F (3, 32) = 6.934, *p*= 0.001, η_p^2=0.394], indicating an interaction effect between age and sex in dichotic listening performance when the stimuli were equally loud in both ears. Follow-up post-hoc tests indicated that females in group one (35-44 years) displayed a significantly lower REA magnitude when the IID was 0 dB than males in group one (35-44 years) [*p*=0.029] as seen in Figure 11. This indicates that males in the youngest age group have a significantly larger REA magnitude than females the same age. Pairwise comparisons also revealed that males in group three (55-64 years) displayed a significantly lower REA magnitude than females of the same age [*p*=0.001] as seen in Figure 11. This indicates that females aged 55-64 have a significantly greater REA magnitude than males the same age.

The second two-way ANOVA was based on based on the level in dB where the REA became a LEA, or the cross-over level. The within group factor was age and the between group factor was sex. The resulting ANOVA was significant [F (3, 32) = 3.768, *p*= 0.020, η_p^2=0.261], indicating a interaction effect between age and sex at the cross-over level from a REA to a LEA. Post-hoc analysis revealed that males in group three (55-64 years) had a significantly lower cross-over point (dB) from REA to LEA than females the same age [*p*=0.016] as seen in Figure 12. This indicates that in females aged 55-64, the REA becomes a LEA when the intensity level in the left ear is much higher than the right compared with males the same age.

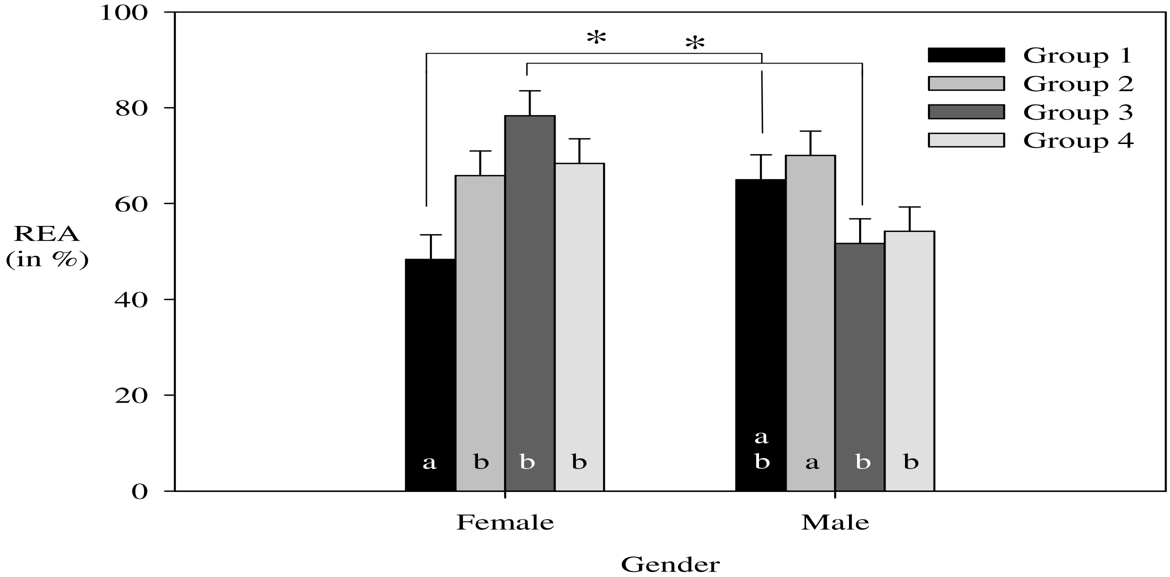

Figure 11. Percentage of times the right ear stimulus was chosen when the IID was 0 dB for males and females in all age groups. * indicates a significant difference between males and females in the same age group, and a/b indicate a significant difference within male and female groups as a function of age. (*p*<0.05).

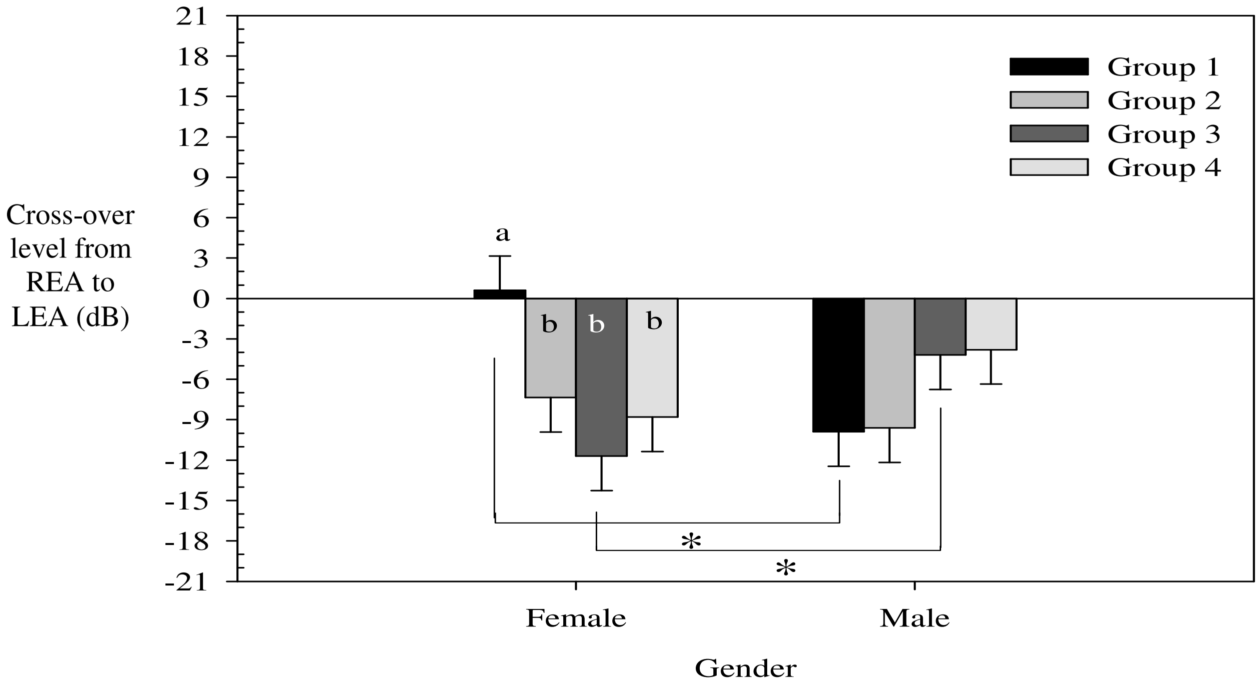

Figure 12. Cross-over level (dB) where the REA becomes a LEA for males and females in all age groups. * indicates a significant difference between males and females in the same age group, and a/b indicate a significant difference within male and female groups as a function of age. (*p*<0.05).

Directed Attention Task: Age

The individual results of the directed attention task for the four groups are shown in Appendix XIII to Appendix XX. The group results can be found in Figure 13 and Table 2.

Group 1 (35-44 years): Participants in group one scored 62% correct in the directed-right task (i.e., they accurately reported the CV syllable presented to the right ear 62% of the time). In the directed-left task, participants scored 46% correct (i.e. they accurately reported the CV syllable presented to the left ear 46% of the time). In general, the 35-44 year old age group showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 2 (45-54 years): In the directed-right task, participants scored 62% correct and in the directed-left task, participants scored 43% correct. The 45-54 year old age group showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 3 (55-64 years): In the directed-right task, participants scored 61% correct. In the directed-left task, participants scored 40% correct. As a rule, the 55-64 year old age group showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 4 (65-74 years): In the directed-right task, participants scored 63% correct while in the directed-left task, participants scored 39% correct. Overall, the 65-74 year old age group showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Examination of the results indicates that all age groups were fairly consistent on both the directed-right and directed-left tasks. All groups scored higher when instructed to attend to the right ear. To evaluate whether directed dichotic listening performance differed as a function of age, two separate ANOVA tests were performed. Findings showed there was no significant difference between the four age groups in the directed-right condition [F (3, 32) = 0.023, p= 0.995, η_p^2=0.002] or the directed-left condition [F (3, 32) = 0.421, p= 0.739, η_p^2=0.038].

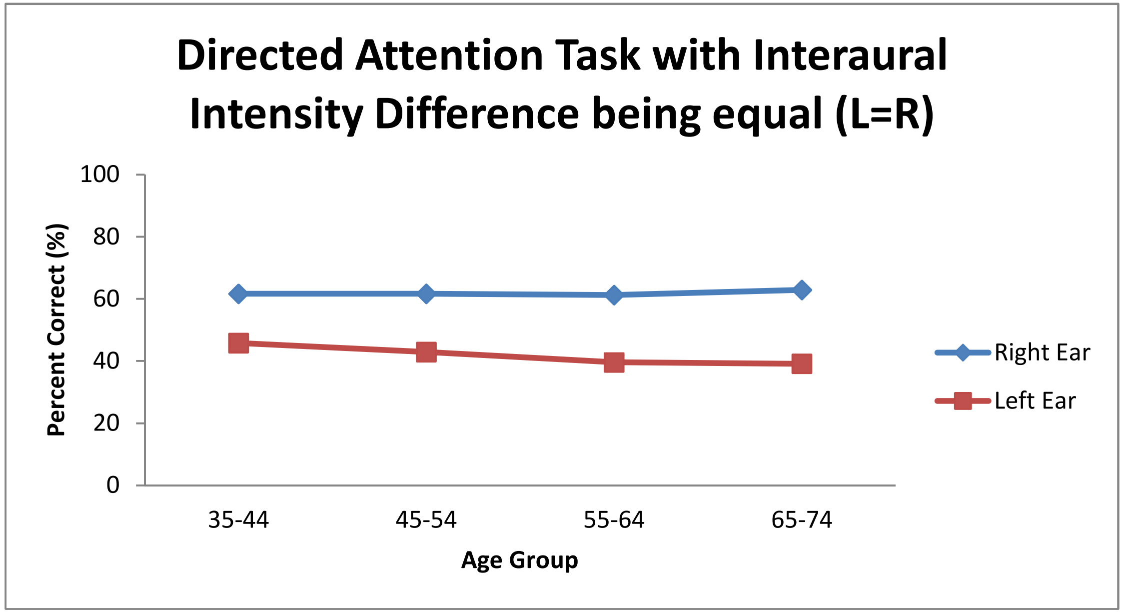

Figure 13. Percent correct for participants across all four age groups (35 to 74 years) collapsed across sex, in the directed attention tasks (directed-left is left ear & directed-right is right ear). These results indicate the percentage correct when participants are instructed to direct their attention to the left or the right.

Table 2. Means and percentages for all four age groups (35-74 years) for the directed attention tasks (directed-left and directed-right). Each participant heard 24 presentations of CV syllables in the directed condition. The table shows the ear in which participants reported hearing the stimuli (left or right) when instructed to direct their attention to either the left or right.

		Ear in which reported stimulus was heard							
		Left				**Right**			
Attention	**Group**	**Mean**	**(%)**	**SD**	**(%)**	**Mean**	**(%)**	**SD**	**(%)**
Directed Left	**1 (35-44)**	11	(45.83)	2	(8.34)	13	(54.17)	2	(8.34)
	2 (45-54)	10.3	(42.92)	4.55	(18.94)	13.7	(57.08)	4.55	(18.94)
	3 (55-64)	9.5	(39.59)	4.17	(17.36)	14.5	(60.41)	4.17	(17.36)
	4 (65-74)	9.4	(39.16)	2.67	(11.13)	14.6	(60.84)	2.67	(11.13)
Directed Right	**1 (35-44)**	9.2	(38.32)	2.86	(11.92)	14.8	(61.68)	2.86	(11.92)
	2 (45-54)	9.2	38.34	4.39	(18.31)	14.8	(61.66)	4.39	(18.31)
	3 (55-64)	9.3	38.75	4.74	(19.73)	14.7	(61.25)	4.74	(19.73)
	4 (65-74)	8.9	37.08	2.28	(9.51)	15.1	(62.92)	2.28	(9.51)

Directed Attention Task: Sex

The individual results of the directed attention task for the female and male groups are shown in Appendix XIII to Appendix XX. The combined results for both groups are shown in Figure 14 and Table 3.

Females: In the directed-right task, participants scored 56% correct (i.e. they accurately reported the CV syllable presented to the right ear 56% of the time). In the directed-left task, participants scored 45% correct (i.e. they accurately reported the CV syllable presented to the left ear 45% of the time). In general, females showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Males: In the directed-right task, participants scored 67% correct and in the directed-left task, participants scored 44% correct. As a general rule, males showed better identification of CVs when attention was directed to the right ear compared with the left.

Examination of the results indicates that females scored a slightly lower percentage correct (56%) than males (67%) in the directed-right condition. Males and females displayed remarkably similar scores on the directed-left task. Both groups scored higher when instructed to attend to the right ear compared with when instructed to direct their attention to the left ear. Two ANOVAs were preformed to evaluate whether directed dichotic listening performance differed as a function of sex. Findings showed there was no significant difference between males and females in the directed-right condition [F (1, 32) = 1.030, p= 0.864, η_p^2=0.001] or the directed-left condition [F (1, 32) = 0.477, p= 0.495, η_p^2=0.015].

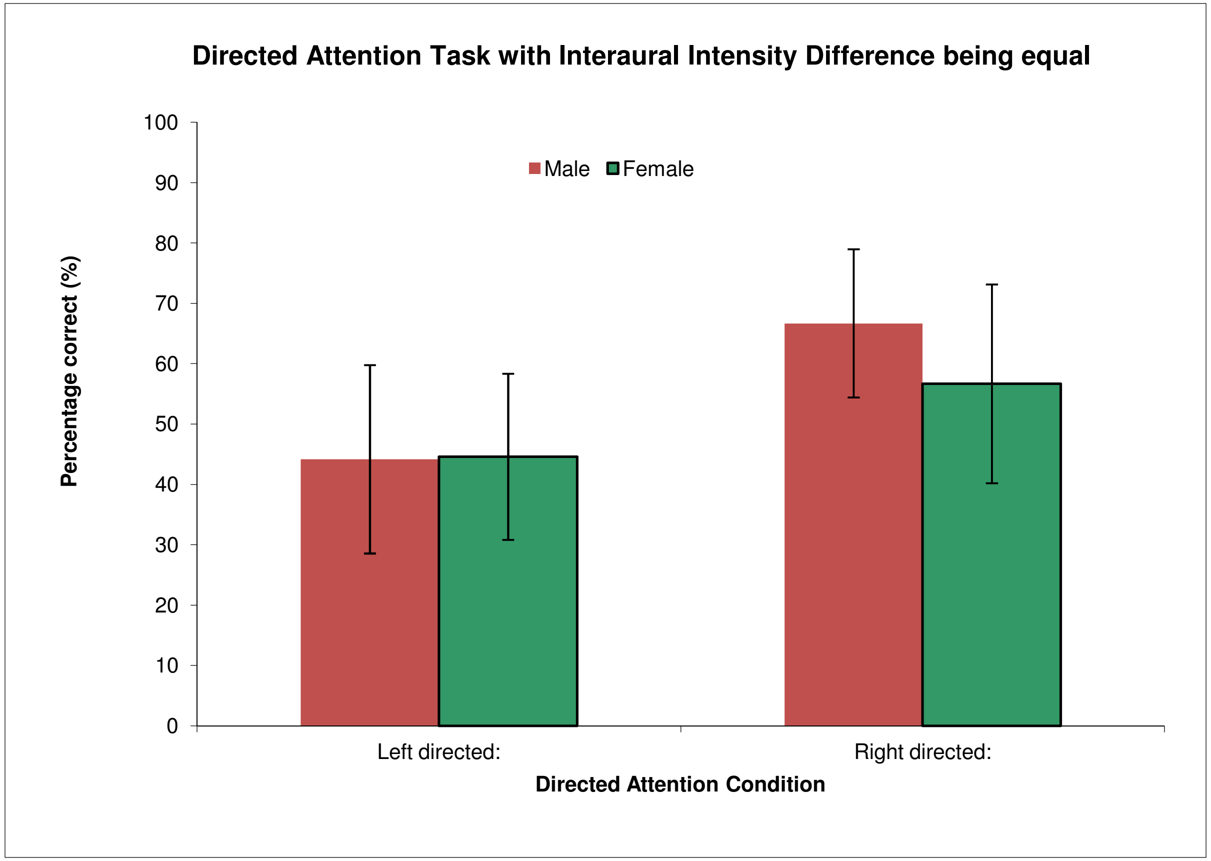

Figure 14. Percent correct for female and male participants collapsed across age groups in the directed attention tasks (directed-left and directed-right). The results indicate the percentage of correct identifications made by the participants when instructed to direct their attention to the left or right.

Table 3. Means and percentages for males and females for the directed attention tasks (directed-left and directed-right). Each participant heard 24 presentations of CV syllables in the directed condition. The table shows the ear in which ear participants reported hearing the stimuli (left or right) when instructed to direct their attention to either the left or right.

		Ear in which reported stimulus was heard							
		Left				**Right**			
Attention	**Group**	**Mean**	**(%)**	**SD**	**(%)**	**Mean**	**(%)**	**SD**	**(%)**
Directed Left	**Female**	10.7	(44.58)	3.30	(13.76)	13.3	(55.42)	3.30	(13.76)
	Male	10.6	(44.17)	3.75	(15.61)	13.4	(55.83)	3.75	(15.61)
Directed Right	**Female**	10.4	(43.33)	3.95	(16.46)	13.6	(56.67)	3.95	(16.46)
	Male	8	(33.33)	2.94	(12.27)	16	(66.67)	2.94	(12.27)

Directed Attention Task: Age and Sex

The individual results of the directed attention task for males and females are shown in Appendix XIII to Appendix XX. The combined results for males and females in all age groups are shown in Figure 15. The combined results for females in all age groups are also summarized in Table 4 and for males this information is found in Table 5.

Females:

Group 1(35-44 years): In the directed-right task, participants scored 59% correct (i.e. they accurately reported the CV syllable presented to the right ear 59% of the time). In the directed-left task, participants scored 46% correct (i.e. they accurately reported the CV syllable presented to the left ear 46% of the time). Overall, females aged 35-44 showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 2(45-54 years): In the directed-right task, participants scored 54% correct. In the directed-left task, participants scored 43% correct. Females aged 45-54 showed better identification of CVs when attention was directed to the right ear compared with the left ear as a general rule.

Group 3(55-64 years): In the directed-right task, females aged 55-64 scored 70% correct, while in the directed-left task participants scored 36% correct. The group tended to show better identification of CVs when attention was directed to the right ear compared with the left.

Group 4(65-74 years): In the directed-right task, participants scored 66% correct, compared with 36% correct in the directed-left task. In general, females aged 65-74 showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Males:

Group 1(35-44 years): In the directed-right task, males aged 35-44 scored 64% correct (i.e. they accurately reported the CV syllable presented to the right ear 64% of the time), while in the directed-left task, participants scored 46% correct. Overall, this group showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 2(45-54 years): In the directed-right task, participants scored 69% correct, and in the directed-left task, participants scored 43% correct. Males aged 45-54 showed better identification of CVs when attention was directed to the right ear compared with the left ear.

Group 3(55-64 years): In the directed-right task, males aged 55-64 scored 53% correct, compared with 43% correct in the directed-left task. This group showed better identification of CVs when attention was directed to the right ear compared with the left ear on the whole.

Group 4(65-74 years): In the directed-right task, participants scored 60% correct and in the directed-left task, participants scored 42% correct. Males aged 65-74 tended to show better identification of CVs when attention was directed to the right ear compared with the left ear.

Examination of the results according to age and sex indicates that all age groups were fairly consistent on both the directed-right and directed-left tasks. All groups scored higher when instructed to attend to the right ear. Males in group two (45-54 years) scored better on the directed-right condition (69%) than females the same age, (54%). This pattern reversed in group three (55-64 years), with males here scoring lower on the directed-right condition

(53%) than females (70%). Females in the two oldest age groups also showed slightly poorer performance on the directed-left condition than males the same age.

To evaluate whether directed dichotic listening performance differed as a function of age and sex, a two-way ANOVA was performed for each condition. The within group factor was age and the between group factor was sex. The results of the main effects for age and sex are reported in earlier sections (see Directed Attention Tasks: Age, and Directed Attention Tasks: Sex). For the directed-right condition, there was no significant age by sex interaction [$F(3, 32) = 2.187$, $p= 0.109$, $\eta_p^2=0.170$]. Likewise, for the directed-left condition, there was no significant age by sex interaction [$F(3, 32) = 0.203$, $p= 0.893$, $\eta_p^2=0.019$].

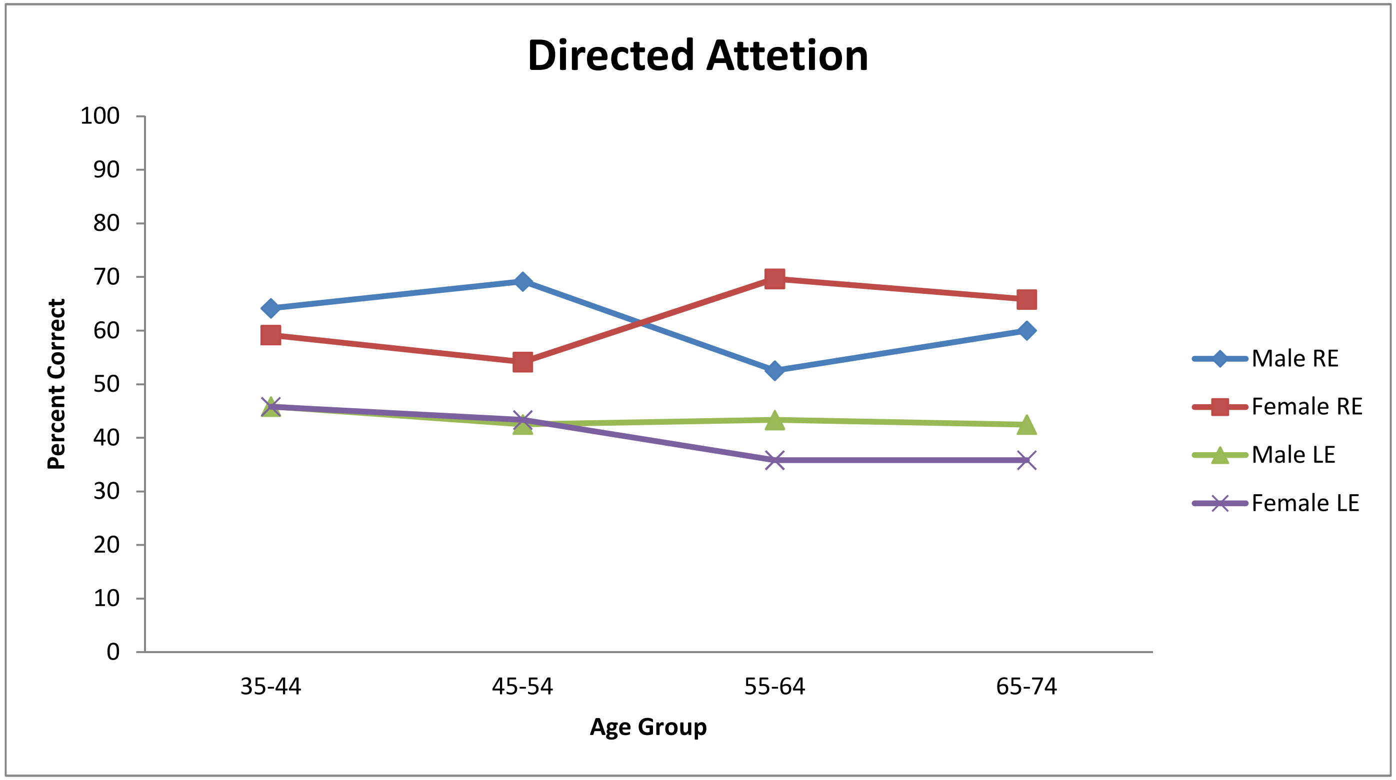

Figure 15. The percentage of correct identifications made by the female and male participants across all four age groups (35-74 years) in the directed attention tasks (directed-left is left ear (LE) and directed-right is right ear (RE)). The results indicate the percentage correct when participants are instructed to direct their attention to the left or right ear.

Table 4. Means and percentages for females in all four age groups (35-74 years) for the directed attention tasks (directed-left and directed-right). Each participant heard 24 presentations of CV syllables in the directed condition. The table indicates instances in which ear participants reported hearing the stimuli (left or right) when instructed to direct their attention to either the left or right.

		Ear in which reported stimulus was heard							
		Left				Right			
Attention	Group	Mean	(%)	SD	(%)	Mean	(%)	SD	(%)
					Female				
Directed Left	1 (35-44)	11	(45.82)	2.55	(10.63)	13	(54.18)	2.55	(10.63)
	2 (45-54)	10.4	(43.34)	4.22	(17.59)	13.6	(56.66)	4.22	(17.59)
	3 (55-64)	8.6	(35.84)	3.85	(16.01)	15.4	(64.16)	3.85	(16.01)
	4 (65-74)	8.6	(35.84)	2.70	(11.24)	15.4	(64.16)	2.70	(11.24)
Directed Right	1 (35-44)	9.8	(40.82)	3.70	(15.43)	14.2	(59.18)	3.70	(15.43)
	2 (45-54)	11	(45.84)	4.53	(18.87)	13	(54.16)	4.53	(18.87)
	3 (55-64)	7.2	(30.02)	2.39	(9.96)	16.8	(69.98)	2.39	(9.96)
	4 (65-74)	8.2	(34.18)	1.64	(6.85)	15.8	(65.82)	1.64	(6.85)

Table 5. Means and percentages for males in all four age groups (35-74 years) for the directed attention tasks (directed-left and directed-right). Each participant heard 24 presentations of CV syllables in the directed condition. The table indicates instances in which ear participants reported hearing the stimuli (left or right) when instructed to direct their attention to either the left or right.

		Ear in which reported stimulus was heard							
		Left				**Right**			
Attention	**Group**	**Mean**	**(%)**	**SD**	**(%)**	**Mean**	**(%)**	**SD**	**(%)**
					Male				
Directed Left	**1 (35-44)**	11	(45.84)	1.58	(6.59)	13	(54.16)	1.58	(6.59)
	2 (45-54)	10.2	(42.5)	5.36	(22.31)	13.8	(57.5)	5.36	(22.31)
	3 (55-64)	10.4	(43.34)	4.72	(19.67)	13.6	(56.66)	4.72	(19.67)
	4 (65-74)	10.2	(42.48)	2.68	(11.18)	13.8	(57.52)	2.68	(11.18)
Directed Right	**1 (35-44)**	8.6	(35.82)	1.95	(8.12)	15.4	(64.18)	1.95	(8.12)
	2 (45-54)	7.4	(30.84)	3.85	(16.05)	16.6	(69.16)	3.85	(16.05)
	3 (55-64)	11.4	(47.48)	8.81	(24.22)	12.6	(52.52)	8.81	(24.22)
	4 (65-74)	9.6	(39.98)	2.79	(11.64)	14.4	(60.02)	2.79	(11.64)

Summary of Major Findings

Undirected Attention Task

1. All groups performed better when listening with the RE compared with the LE, as shown by a REA.
2. There was no significant age effect or sex effect overall in dichotic listening performance when the stimuli were equally loud in both ears (IID = 0 dB).
3. There was a significant interaction effect between age and sex in dichotic listening performance when the stimuli were equally loud in both ears (IID = 0 dB).
4. There was no significant age or sex effect overall in dichotic listening performance in the level in dB where the REA became a LEA.
5. There was a significant interaction effect between age and sex in dichotic listening performance in the level in dB where the REA became a LEA.

Directed Attention Task

1. All participants performed better in the directed-right condition and poorer in the directed-left condition.
2. Performance remained relatively stable across age and by sex.
3. There were no statistically significant differences on the directed-right or directed-left conditions.

Discussion

The purpose of this study was to investigate possible differences in cerebral lateralisation of speech processing between younger and older adults, and between males and females, as inferred using dichotic listening tasks. Based on examination of 40 participants, six null hypotheses were posed. A discussion of each of these hypotheses follows.

Undirected Attention Dichotic Listening Task

1. *There will be no significant difference between younger and older adults in the magnitude of the REA at equal intraaural intensity.*

It was hypothesized that there would be no significant difference in REA magnitude with increasing age. Across the four age groups, the magnitude of the REA ranged from 57% (35-44 years) to 68% (55-64 years). Overall, there was no statistically significant age effect in the magnitude of the REA across age groups. Therefore the null hypothesis is accepted.

The results obtained for the present group of participants can be compared to the findings of Jerger et al. (1994). The authors of this study examined dichotic listening in a group of 356 participants aged 9 to 89 years, using sentence stimuli at equal intraaural intensity. Findings of this study revealed that there was little difference between the left and right ears in dichotic listening performance up until 30 years of age. Findings also indicated a significantly greater magnitude in the REA with increasing age from aged 30. The REA became even more pronounced from the 60th decade onwards. This finding could not be attributed to simple differences in hearing thresholds between the ears. The results of the present study agree with Jerger et al. in regard to a prevalent REA in older adults, with all of the age groups showing an REA equal to, or in excess of 57%. However, the present study did not find a significant age-related increase in REA magnitude.

Findings of the present study can also be compared to Bellis and Wilber (2001) who investigated dichotic listening based on digit recall in 120 participants aged 25 to 70 years. Similar to Jerger et al. (1994), the researchers found that, as well as an overall decline in accuracy in both ears on the undirected listening task, there was a significant increase in REA magnitude from the age of 55 years onwards.

Several possibilities are offered for the apparent differences in performance of the present group of adults compared with both Jerger et al. (1994) and Bellis and Wilber (2001). First, the sample sizes used in the previous studies were considerably larger than the present study. The smaller sample size in the present study may have resulted in more within-group and between-group variability in performance. As such, any age-related differences in performance may have been masked as a result of participant variability. Further, the study by Jerger et al. encompassed a much greater age range of both younger and older participants (9-89 years) than the present study (35-74 years). The inclusion of younger and older participants in the present study may have been more revealing of possible age differences in dichotic listening performance.

While there may have been sampling issues contributing to the present results, it is interesting to consider the role of test stimuli upon dichotic listening performance. Bellis and Wilber (2001) examined dichotic listening using digit recall, while Jerger et al. (1994) used sentences, and both studies found an age-related difference in performance. Both digit recall and sentence recall paradigms involve a working memory component, whereby items that are presented first but not immediately recalled must be retained in short-term working memory before they are reported. The present study used CV stimuli, which are linguistically simpler than digit and sentence recall stimuli, and which were recalled immediately from a forced choice paradigm. The use of such stimuli resulted in no apparent age-related differences in dichotic listening. Therefore it is possible that digit and sentence recall places a much greater demand on cognition and memory. Penner, Schlafi, Opwis and Hugdahl (2009) found that increasing cognitive demand increases the REA magnitude, which may in part explain the significant decline in performance with increasing age in these past studies.

2. *There will be no significant difference in the REA magnitude between males and females as a function of increasing age at equal intraaural intensity.*

It was hypothesized there would be no significant difference in the magnitude of the REA between males and females, and that no sex differences would be apparent as a function of age. In the present study, findings indicated no significant difference between males and females in undirected dichotic listening performance collapsed across age groups. However, there was a significant interaction effect between age and sex. This hypothesis was motivated by past dichotic listening studies that have found sex differences in interhemispheric function as indicated by dichotic listening performance. Noteworthy among these studies is a report by Bellis and Wilber (2001). These researchers found men to show a stronger REA compared to women between 20-75 years of age, with a significant difference apparent at 35-40 years. A sex difference in the REA was also reported by Jerger et al. (1994), with males showing a greater REA than females, however this sex difference was not confirmed statistically. More recently, a large-scale study (n=1782) by Hirnstein et al. (in press) found no evidence of an overall sex difference in dichotic listening using CV stimuli, but a significant interaction between age and sex. In this study, female adolescents (10-15 years) had a stronger REA magnitude than their male counterparts. This trend reversed in young adult males (16-49 years), with this group showing a significantly greater REA than young adult females.

In the current study, sex differences in the magnitude of the REA were seen between-groups, with females in group one (35-44 years) displaying a significantly lower percentage of times the right ear stimulus was chosen when the IID was 0 dB than males at the same age.

That is, young males had a significantly larger REA magnitude than young females. This pattern of a stronger REA in males prior to 55 years of age appears to agree with past studies. However, there was also a significant difference between women and men in group two (55-64 years). Yet, in this instance, females showed a stronger REA magnitude than males. On the basis of these age-specific findings it is difficult to definitively conclude that a sex difference is apparent for an REA of equal intraaural intensity. Therefore the null hypothesis is partially accepted.

Based on examination of the present results in comparison to the past studies identifying a sex difference in REA, it is perhaps not surprising to find no definitive sex differences were apparent. The difference observed by Bellis and Wilber (2001) was only found for one specific age group (35-40 years), the results by Jerger et al. (1994) were not confirmed statistically, and Hirnstein et al. (in press) found a difference between adolescents and adults. Hirnstein et al. suggested that findings could be due to differences in the anatomy of the corpus callosum, whereby interhemispheric transfer of information becomes less efficient with age. There was also a suggestion that sex hormones such as estrogen and testosterone could have a role to play. Overall, if sex differences in dichotic listening do exist, the likelihood of an age-dependent difference is relatively small.

3. *There will be no significant difference between younger and older adults in the REA magnitude when the IID is altered.*

It was hypothesized that there would be no significant difference with increasing age in REA magnitude when the IID was altered in an undirected attention dichotic listening task. Across the four age groups, collapsed across sex, the average cross-over level (dB) from a REA to a LEA ranged from -5 dB (35-44 years) to -8 dB (45-54 years). These results indicate that all age groups required the CVs to be at least 5 dB louder in the left ear than the right for the REA to become a LEA. Overall, there was no statistically significant difference in the cross-over level among all four age groups. Therefore the null hypothesis is accepted.

Past studies investigating age–related changes in dichotic listening have found a progressively larger REA with increasing age (Hirnstein et al, in press). In the present study, this finding was explored further by altering the IID during undirected attention dichotic listening tasks. Results by Tallus et al. (2007) and Westerhausen et al. (2009) have shown that altering the IID serves to manipulate the magnitude of the REA in both undirected and directed attention dichotic listening tasks. In undirected attention tasks, this change in REA magnitude is thought to be reflective of bottom-up speech processing. Bottom-up processing is based on a structural model. In the case of dichotic listening, there is a left-hemisphere advantage for processing language. This causes a signal loss or delay for information presented to the left ear, related to an additional interhemispheric transfer step from the right to the left auditory cortex. This influences performance in dichotic listening tasks and results in the REA (Kimura, 1961). However, studies have shown that when the IID is altered, higher intensity speech sounds have a better chance of being processed, irrespective of which ear they are presented to (Hugdahl et al., 2008b). This is thought to be due to either compensation in colossal transfer due to increased intensity, or an involuntary direction of attention towards the louder ear (Hugdahl et al., 2008a).

The IID methodology was used in the present study to more critically evaluate whether an age-related difference in the REA was evident. The results of the present study failed to confirm past results. Interestingly, all age groups showed a persistence of the REA, even when the signal presented to the left ear was 5 dB louder than that to the right ear. This is consistent with the work of Hugdahl et al. (2008b) who examined the minimum IID required to shift a REA to a LEA using CV stimuli in 33 healthy participants. These researchers found a clear REA at 0 dB IID, and when the intensity was modulated to favour the left ear, a REA persisted until the stimuli were 9 dB more intense in the left ear.

Similar to the results found for an IID of 0 dB, matters related to sample size and/or stimulus type may have contributed to the lack of an obvious age difference. However, the detailed testing based on altering the IID provides compelling evidence across participants that an age-related difference in the REA was not found.

4. *There will be no significant difference between males and females as a function of increasing age in REA magnitude when the IID is altered.*

It was hypothesized there would be no significant difference in the REA magnitude between men and women, and that a sex difference would not be apparent as a function of age. In the present study, findings indicated no significant difference between sexes when collapsed across age groups, thereby providing support for the null hypothesis. The average cross-over level (dB) from a REA to a LEA for female participants across all four age groups ranged from -2 dB (35-44 years) to -11 dB (55-64 years). For males, this ranged from -2 dB (55-64 years) to -9 dB (45-54 years). These results indicate that there was a persistent REA among all participants when the IID was altered, with both males and females requiring the CVs to be at least 2 dB louder in the left ear than the right for the REA to become a LEA.

A significant interaction between age and sex was found. Between group analysis indicated that females in group three (55-64 years) had a significantly higher cross-over level (dB) from REA to LEA than males at the same age. This means that in females aged 55-64, the REA becomes a LEA only when the stimuli are much more intense in the left ear than the right compared with males the same age. Recall that Bellis and Wilber (2001) proposed a sex and age dependent difference in interhemispheric function. Specifically, men between the ages of 35-40 showed a stronger REA compared to women. However, between the ages of

55-60 years women tended to “catch-up” with men and show a similarly robust REA. The sex differences observed in the present groups aged 55-64 tends to correspond with past results of Bellis and Wilber. Still, the overall pattern observed based on altering the IID provides strong evidence that sex-related differences in the REA are minimal. Therefore the null hypothesis is partially accepted.

Directed Attention Dichotic Listening Task

5. *There will be no significant difference between younger and older adults in the magnitude of the REA at equal intraaural intensity.*

The results of the directed attention task can be discussed and analysed in two ways. The first is to consider performance on the directed-right task, which provides a direct indication of the magnitude of the REA. Alternatively, it is useful to examine performance on the directed-left task, which provides an indirect or inferential measurement of the REA. It was hypothesized that there would be no significant difference in the REA magnitude with increasing age in a directed attention dichotic listening task at equal intraaural intensity. On the directed-right task, participants from the four age groups were remarkably similar, ranging from 61-63% correct identification of CVs (Figure 13). Not surprisingly, the groups performed more poorly on the directed-left task. Group performance ranged from 39-46% correct (Figure 13), indicating that greater than 50% of the time, participants selected the CV presented to the right ear. On the basis of the combined results, the null hypothesis is accepted.

The results obtained for the present groups of participants can be compared to a study by Foundas et al. (2006). The authors examined dichotic listening using three conditions (undirected, directed-right & directed-left), in 51 left and right-handed participants with an average age of 30 years. The authors examined recall responses to CV stimuli according to the attended ear. The researchers found a pronounced REA in the directed-right task. In this condition, right-handed males scored an average of 66% correct, while females scored 57%. Findings also revealed a weaker REA, or a LEA in the directed-left task, with right handed males correctly identifying 53% of presentations, and females correctly identifying 49%. This indicates that directing attention can manipulate the magnitude of the REA.

Kinsbourne (1970) was the first to examine the effects of attention on dichotic listening, believing that Kimura's reports of the REA could not be explained entirely by bottom-up processing. Kinsbourne hypothesized that cognitive modulation was at play, and that the REA may be 1) enhanced by priming the left hemisphere to anticipate speech, and 2) suppressing presentations to the left ear due to this anticipation, both resulting in the REA. This process of anticipation by the left hemisphere for speech stimuli is referred to as top-down processing. Therefore, directing attention is thought to demonstrate enhancement of speech processing which can occur for the directed ear whether it is left or right, reflecting top-down processing.

In the current study, all age groups showed better, but not significantly better identification of CVs when attention was directed to the right ear compared to when attention was directed to the left ear. This follows past studies where there was a more pronounced REA in the directed-right condition and a present, but less robust REA in the direct-left condition.

6. *There will be no significant difference between males and females as a function of increasing age in the magnitude of the REA at equal intraaural intensity.*

It was hypothesized that there would be no significant difference in the REA magnitude between males and females collapsed across age groups, and no sex differences as a function of increasing age in a directed attention task. In the present study, the overall performance for females on the directed-right task was lower (56%) compared to males (67%). Both sexes scored consistently lower on the directed-left condition, with females scoring 45% and males scoring 44%. None of the differences were statistically significant.

Across age groups, males and females scored higher when instructed to attend to the right ear. For females, scores in the directed-right condition ranged from 54% (45-54 years) to 70%, (65-74 years) while for the directed-left condition, scores ranged from 36% (55-75 years) to 46% (35-44 years). For males, scores in the directed-right condition ranged from 53% (55-64 years) to 69% (45-54 years) and the directed-left scores ranged from 42% (65-74 years) to 46% (35-44 years).

Males in group two (45-54 years) scored better on the directed-right condition (69%) than females the same age, (54%). This pattern reversed in group three (55-64 years), with females scoring higher on the directed-right condition (70%) than males (53%). Females in the two oldest age groups also showed slightly poorer performance on the directed-left condition than males the same age.

These results closely parallel the results obtained in the undirected attention task, with males showing a stronger REA prior to 55 years of age. By 55 years, females tend to “catch-up” to males, with a similar REA for both sexes evident by 65 years of age. On the basis of these combined results, the null hypothesis is accepted.

Models of Hemispheric Asymmetry, Peripheral Hearing, Working Memory and Aging

It is well known that the hemispheres of the brain are anatomically and functionally asymmetric (Suganthy et al., 2003). One clear functional hemispheric asymmetry is in the processing of verbal and non-verbal information. The left hemisphere, namely the left temporal lobe, has a specialised role in recognising auditorily-presented verbal information and language processing, based on the location of Wernicke’s area (Kimura, 1961). The right hemisphere has a greater role in processing non-verbal information. There is evidence that these asymmetries are affected by conditions that alter the anatomical and functional integrity of the brain, such as aging (Dolcos et al., 2002). The two theoretical models discussed in the introduction (the right hemisphere aging model and the HAROLD model) provide different views of age-related changes in hemispheric asymmetry.

The right hemisphere aging model proposes that the right hemisphere shows a greater and earlier age-related structural and cognitive decline than the left hemisphere, which could explain the increased magnitude in the REA with aging. Evidence for this model is mixed. Goldstein and Shelly (1981) used the Wechsler Adult Intelligence Scale (WAIS) to show that elderly patients were less impaired on a verbal component (which relies on the left hemisphere) than a non-verbal, spatial one (which relies on the right hemisphere). The authors concluded that this indicated a greater decline in the function of the right hemisphere with aging. Elias and Kinsbourne (1974) however, found that when variables such as task complexity were controlled, there were no significant differences on verbal and non-verbal tasks, which does not support the idea that right hemisphere processing is selectively affected by aging. The HAROLD model proposes that PFC activity during performance on cognitive tasks tends to be more symmetrical in older than in younger adults. There is growing support for the idea that the age-related asymmetry seen through the REA in older adults is due to the HAROLD model, which causes functional compensation at the level of the brain, rather than general structural decline of either hemisphere (Cabeza, 2002; Dolcos et al., 2002). Ultimately, the two models are not mutually exclusive, and it is possible both are operational in different regions of the brain (Dolcos et al., 2002).

The results of the present study indicated that although all groups displayed a REA on dichotic listening tasks using CV stimuli, there were no significant age or sex effects overall on directed or undirected attention listening performance when the stimuli were equally loud in both ears, nor when the IID was altered. That fact that performance remained relatively stable across age groups is inconsistent with many past reports of dichotic listening that reveal an increasing REA with increasing age, but somewhat consistent with the HAROLD model, whereby older adults are thought to employ additional resources from the subdominant hemisphere, resulting in more symmetrical brain organization (Cabeza, 2002). It is worth noting that studies examining dichotic listening under these models have not accounted for the effects of IID and hearing loss. It is therefore possible that different models of hemispheric asymmetry and aging exist for dichotic listening performance, depending on factors such as stimulus type and intensity, and severity of hearing loss.

It has been suggested that age-related changes in speech understanding both monotically and dichotically, have been confounded with concomitant age-related changes in peripheral hearing sensitivity (Jerger et al., 1994). However, when the degree of hearing loss has been controlled for, the performance of older subjects is more comparable to younger ones (McCoy, Butler & Broekhoff, 1977). In addition to working memory influences on speech stimuli, such as digits and sentences, these types of stimuli also require preserved high frequency hearing. Therefore, the spectral features of dichotic listening stimuli may have some additional adverse effects on dichotic listening performance in older adults. In the present study, age-related differences in peripheral hearing were accounted for. The six CV stimuli used (/ba/, /da/, /ga/, /pa/, /ta/, /ka/) all contain information predominantly below 4000 Hz (Katz, Medwetsky, Burkard & Hood, 2009) where the majority of subjects had normal or near normal hearing. Additionally, a sophisticated approach to pre-test calibration was performed to establish the interaural intensity balance for each individual, in order to account for any audiometric asymmetries of individual participants. It is possible that these considerations in regard to the presentation of stimuli provided an “advantage” to the older participants. This advantage was evident by the lack of any age or sex differences.

It is also worth re-emphasizing the impact of working memory on the results obtained in the present study. Working memory refers to a system for temporary storage and manipulation of information in the brain, necessary for complex tasks such as language comprehension and other cognitive operations (Baddeley, 1992). Working memory requires the simultaneous storage and processing of information. Hallgren et al. (2001) examined the effects of chronological age on dichotic speech tests using a range of speech stimuli, including digits, CVs and sentences, to determine whether dichotic listening was related to cognitive ability. The effects of attention were also examined. Findings revealed that test material, way of reporting, and attention all affected performance on dichotic listening. Reaction time was also slower for the older group. The authors hypothesized that although peripheral hearing sensitivity may have had some role to play, it did not account for all differences seen between older and younger participants. It is therefore likely that any age-related differences in the REA are due to a combination of reduced central processing, and age-related changes in cognitive function.

When thinking about the effects of working memory in the context of the present study, it is worth noting that in both the directed and undirected attention conditions, participants only had to recognize and report one CV in a closed-set paradigm with two possible options. It is therefore likely that these results were more auditory-modality specific, as there was less of a demand on cognition than previous studies. Bellis and Wilber (2001) used dichotic digits, with participants having to recognize, remember and recall four digits while Jerger et al. (1994) used sentences, with participants having to recognize, remember and recall multiple words in order. Penner et al. (2009) found that increasing cognitive demand on working memory increased the magnitude of the REA. It is likely that during both sentence and digit recall there was a greater demand on cognitive processing, which may have explained the significant age effects seen in the earlier studies.

Limitations

The limitations of the present study are discussed in the following sections, which include issues related to participant recruitment, handedness, severity of hearing loss, and a possible ordering effect.

Participant Recruitment

In the present study, ten participants (five males and five females) comprised each group, with a total of forty participants. This sample size was likely to yield low statistical power and contribute to some within-group and between-group variability. The statistical power of a test is the probability that it will correctly lead to the rejection of a false null hypothesis (Greene 2000) or in other words, the probability that it will result in the conclusion that the phenomenon exists (Cohen, 1988). Past research examining cerebral lateralization on dichotic listening tasks has varied considerably, ranging from 1 (Sparks & Geschwind, 1968) to as many as 1782 participants (Hirnstein et al., in press). Although the pattern in performance observed in the present study was one of minimal change or difference, the results should be considered preliminary, and caution is warranted when generalizing these findings to the broader population.

Participants in this study were all right-handed and there was no attempt to recruit left-handed adults. Handedness is a factor that may affect the processing of speech stimuli (Foundas et al., 2006). Oftentimes, there is a greater instance of a LEA in left-handed individuals, because the location of the language dominant hemisphere can be on the right side in these individuals (Knecht et al., 2000). In addition, studies examining handedness have shown a greater shift in listening bias, or ability to manipulate the ear advantage, especially on directed attention tasks (Cowell & Hugdahl, 2000). It is therefore important to stress that the results of this study are confined to right-handed individuals only.

Severity of Hearing Loss

The current study included participants with normal hearing and symmetrical sensorineural hearing loss. Of the 40 participants in the present study, the lowest overall PTA value for any participant in one ear was 0 dB HL, and the highest was 45 dB HL. Younger participants typically had lower PTAs than older participants. Individual participants were only able to participate in this study if the PTA of their right and left ears were within 5 dB of each other. All participants also completed a baseline perceptual calibration task to account for any perceptual asymmetries in their hearing which would influence the results when changing the IID.

It is worth noting that even though the overall intensity delivered through the headphones was the same for every participant, those individuals with more significant hearing loss would have been receiving a less intense signal by the time it reached the cochlea. Further, when damage occurs at the cochlear level, clarity as well as intensity of the signal is reduced (Katz et al., 2009). Therefore this signal may have been less clear for these individuals compared to participants who had normal hearing. It is thought that untreated hearing loss can lead to auditory deprivation (Silman, Gelfand & Silverman, 1984), although the idea remains a controversial one in the field of audiology. It is difficult to know the precise duration of hearing loss for each of the participants with a PTA of >20 dBHL in the study, but given that only one participant wore hearing aids, it is possible that those with any degree of hearing loss may have been experiencing some level of altered cerebral processing due to auditory deprivation. Although the calibration ensured the best, most equal intensity stimuli possible was delivered to each ear, it could not account for such factors at the level of the cochlea or the brain.

Order Effects

An ordering effect is a testing phenomenon in which measures are consistently given in the same sequence, creating possible influences on subsequent responses (Portney & Watkins, 2000). In the current study, an ordering effect may have arisen due to all participants starting with the undirected dichotic listening task followed by the directed dichotic listening task. By undertaking the undirected task first, participants were kept naive in their listening. This was done to ensure that during the undirected task no attentional effects occurred. If the directed task had been completed first, participants may have been attending to a specific ear unintentionally in the following undirected attention task. In spite of this rationale, it is possible that performance in the present group of participants was affected by the sequence of dichotic listening tasks.

Clinical Implications

The first clinical implication of the current study is the use of dichotic listening as a means of diagnosing auditory processing difficulties in older adults. Currently, diagnosis of auditory processing difficulties is often made using a battery of tests, some of which include dichotic measures. Typically these dichotic tests utilise digit stimuli (Bellis, 2003). Adjacent to collection of dichotic digit stimuli, performance of dichotic listening using CVs could be used as a supplement to the diagnosis, as this method may provide different information on auditory processing. CVs could even be used as an alternative to digits, given that they are likely to place less of a demand on working memory.

The second implication of this study is the use of dichotic listening to explore laterality and cognitive impairments in clinical populations other than those who have communication difficulties such as hearing loss and auditory processing difficulties. Past research has supported that dichotic listening can be used to examine these populations, such as those with schizophrenia and other mental illness (Hugdahl et al., 2003; Loberg, Hugdahl

& Green, 1999). These studies have shown that patients with schizophrenia are less able to modulate the REA when asked to direct their attention and report only the stimuli heard in the left ear. However when instructed to report only what they heard in the right ear, they are able to modulate the REA. The controls in these studies, as well as other studies (Hugdahl & Anderson, 1986) have shown the ability to modulate the REA by increasing the response when attending to the right ear, and decreasing the effect when attending to the left ear. The finding that those with schizophrenia find it difficult to modulate the REA when attention is directed left it thought to reflect a difficulty in top-down cognitive control. As the demands of attending to each ear are theoretically the same, more research is needed to discover why this difficulty only occurs when attention is directed to the left ear in patients with schizophrenia (Hugdahl et al., 2003; Hugdahl et al., 2008b; Loberg et al., 1999).

Directions for Future Research

It has been more than 50 years since the groundbreaking study by Kimura first demonstrating the REA (Kimura, 1961). Since then, there has been great diversity in dichotic listening research, with topics ranging from healthy individuals across the entire age span, to those with brain tumours and even dementia. Both behavioural and electrophysiological techniques have been utilised. The effects of nicotine and hormones have been examined, as have sex differences, dyslexia, language disorders, auditory processing difficulties, stuttering and attention (Hugdahl, 2011).

Past research examining the effects of aging and gender using dichotic listening tasks has enlisted up to 1782 participants (Hirnstein et al., in press). To validate the findings of the present study, a larger sample size would be beneficial to decrease within- and between-group variability, and to increase the statistical power found in the present study. This would allow for the ability to generalize findings to the population, and to validate this new proposed model of hemispheric asymmetry in terms of aging and sex when CV stimuli are used. Future studies should also include right- and left-handed participants so that further analysis can be made into the effects of using an IID paradigm with increasing age.

The examination of dichotic listening using CV stimuli in younger, as well as older age groups, would allow for more complete conclusions to be drawn regarding hemispheric asymmetry across the lifespan. This is important in order to gain a more complete understanding of the REA, and greater insight into the development of, and changes to hemispheric asymmetry with age. To do this, populations such as children and the elderly would need to be examined using dichotic listening. However, due to the need for concentration and motivation to complete the listening tasks, children need to be at an age where they have the ability to complete the tasks. Some studies have suggested that cerebral lateralization for speech information may be present in the first few years of life, (Eimas, Siqueland, Jusczyk & Vigorito, 1971) but is generally accepted that tests of auditory processing should only be completed from 7 years of age onwards (Bellis, 2003).

Further, past research using dichotic listening in patients with conditions such as dementia (Bouma & Gootjes, 2011) have shown significantly reduced performance on a dichotic digits paradigm, when attending to the left ear. Future research could examine the effects of using a CV-based dichotic listening task, to determine whether lessening the demands on working memory has an impact on these populations.

Several authors have utilised brain imaging techniques such as functional magnetic resonance imaging (fMRI) (Falkenberg, Specht & Westerhausen, 2011) to examine brain activity during dichotic speech perception. Falkenberg et al. (2011) utilised CV stimuli of varying IIDs to examine the REA both behaviourally and electrophysiologically in 40 healthy adults. Findings revealed that two brain networks were involved, with the pathway activated dependant on the level of attention and cognitive demand involved. In future, it would be worthwhile using CV-based dichotic listening tasks and varying the IID to inferentially examine the networks activated in patients with known neurological lesions under fMRI. This would allow for a cost effective, minimally invasive examination of cerebral lateralization.

Finally, future studies could explore the effects of altering the IID on various types of dichotic speech stimuli. While previous studies have examined the effects of stimuli such as sentences (Jerger et al., 1994) and digits (Bellis & Wilber, 2001) at equal intraaural intensity, there has been little research done examining the effects of altering the IID using these stimuli. Tallus et al. (2007) and Westerhausen et al. (2009) have shown that altering the level of CV stimuli presented to each ear can manipulate the magnitude of the REA. It seems reasonable to predict that altering the IID during presentations of dichotic digits and sentences may alter the REA to a greater degree due to the increased demands placed on working memory. Such a study would allow for further validation of this proposed model of hemispheric asymmetry using CV stimuli.

Conclusion

Using dichotic listening via CVs to determine cerebral laterality for speech processing found that older adults did not differ significantly from younger adults in an undirected attention dichotic listening task. Some significant interaction effects did exist between age and sex. The undirected attention results indicated that all age groups had a REA for processing speech information, and the magnitude of this REA remained relatively consistent across time. The cross-over level at which the REA became a LEA was also indicative of a stronger left hemisphere advantage for processing speech, with the cross-over level occurring when the stimuli were more intense (dB) in the left ear for all groups of participants. The cross-over level also remained consistent across time. The overall findings from the undirected listening task do not offer strong support for the suggestion of age or sex differences in dichotic listening using CV stimuli.

The findings for directed attention paralleled those found for undirected attention. Whether there is indirect or direct attention placed on the processing of CV stimuli, there does not appear to be a strong age or sex difference in dichotic listening performance. The overall finding that younger males and females do not differ from older males and females in the directed attention task may indicate that the form of speech processing during this task, i.e. recalling CV stimuli, is not discriminatory of the aging processes in the brain.

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Appendix I

Edinburgh Handedness Inventory (Oldfield, 1971)

The Edinburgh Handedness Inventory Questionnaire

Date:

Time:

Participant:

Age:

Please check the box that applies to you.

		Which hand do you prefer? LEFT	RIGHT	EITHER	Do you ever use the other hand? YES	NO
1	Writing					
2	Drawing					
3	Throwing					
4	Scissors					
5	Toothbrush					
6	Knife (without a fork)					
7	Spoon					
8	Rake (upper hand)					
9	Striking a match or lighter					
10	Opening a box (lid)					

a	Which foot do you prefer to kick with?			
b	Which eye do you use when using only one?			

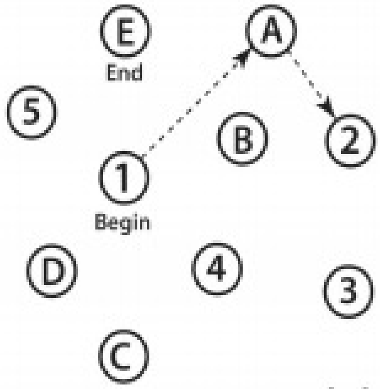
Appendix II

Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005)

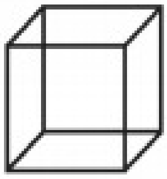
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

Education :
Sex :
Date of birth :
DATE :

VISUOSPATIAL / EXECUTIVE



[ ]



Copy cube

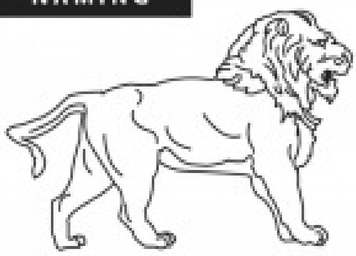
[ ]

Draw CLOCK (Ten past eleven)
(3 points)

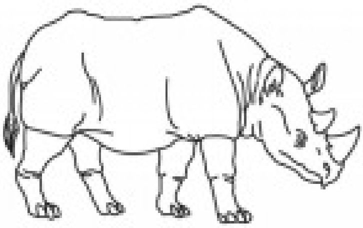
[ ] Contour [ ] Numbers [ ] Hands

POINTS ___/5

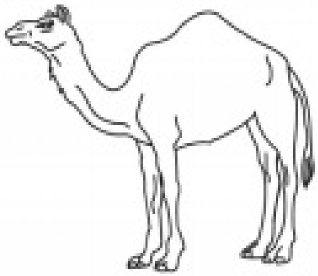
NAMING



[ ]



[ ]



[ ]

___/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 ___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** ___/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] ___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words) ___/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler ___/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	___/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City ___/6

 www.mocatest.org Normal ≥ 26 / 30 TOTAL ___/30
Add 1 point if ≤ 12 yr edu

Administered by: ____________________

Montreal Cognitive Assessment
(MoCA)

Administration and Scoring Instructions

The Montreal Cognitive Assessment (MoCA) was designed as a rapid screening instrument for mild cognitive dysfunction. It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. Time to administer the MoCA is approximately 10 minutes. The total possible score is 30 points; a score of 26 or above is considered normal.

1. <u>Alternating Trail Making</u>:

<u>Administration</u>: The examiner instructs the subject: *"Please draw a line, going from a number to a letter in ascending order. Begin here* [point to (1)] *and draw a line from 1 then to A then to 2 and so on. End here* [point to (E)]."

<u>Scoring</u>: Allocate one point if the subject successfully draws the following pattern:
1 –A- 2- B- 3- C- 4- D- 5- E, without drawing any lines that cross. Any error that is not immediately self-corrected earns a score of 0.

2. <u>Visuoconstructional Skills (Cube)</u>:

<u>Administration</u>: The examiner gives the following instructions, pointing to the **cube**: "*Copy this drawing as accurately as you can, in the space below*".

<u>Scoring</u>: One point is allocated for a correctly executed drawing.
• Drawing must be three-dimensional
• All lines are drawn
• No line is added
• Lines are relatively parallel and their length is similar (rectangular prisms are accepted)

A point is not assigned if any of the above-criteria are not met.

3. <u>Visuoconstructional Skills (Clock)</u>:

<u>Administration</u>: Indicate the right third of the space and give the following instructions: *"Draw a clock. Put in all the numbers and set the time to 10 past 11"*.

<u>Scoring</u>: One point is allocated for each of the following three criteria:
• Contour (1 pt.): the clock face must be a circle with only minor distortion acceptable (e.g., slight imperfection on closing the circle);
• Numbers (1 pt.): all clock numbers must be present with no additional numbers; numbers must be in the correct order and placed in the approximate quadrants on the clock face; Roman numerals are acceptable; numbers can be placed outside the circle contour;
• Hands (1 pt.): there must be two hands jointly indicating the correct time; the hour hand must be clearly shorter than the minute hand; hands must be centred within the clock face with their junction close to the clock centre.

A point is not assigned for a given element if any of the above-criteria are not met.

4. Naming:

Administration: Beginning on the left, point to each figure and say: *"Tell me the name of this animal"*.

Scoring: One point each is given for the following responses: (1) lion (2) rhinoceros or rhino (3) camel or dromedary.

5. Memory:

Administration: The examiner reads a list of 5 words at a rate of one per second, giving the following instructions: *"This is a memory test. I am going to read a list of words that you will have to remember now and later on. Listen carefully. When I am through, tell me as many words as you can remember. It doesn't matter in what order you say them"*. Mark a check in the allocated space for each word the subject produces on this first trial. When the subject indicates that (s)he has finished (has recalled all words), or can recall no more words, read the list a second time with the following instructions: *"I am going to read the same list for a second time. Try to remember and tell me as many words as you can, including words you said the first time."* Put a check in the allocated space for each word the subject recalls after the second trial.
At the end of the second trial, inform the subject that (s)he will be asked to recall these words again by saying, *"I will ask you to recall those words again at the end of the test."*

Scoring: No points are given for Trials One and Two.

6. Attention:

Forward Digit Span: Administration: Give the following instruction: "*I am going to say some numbers and when I am through, repeat them to me exactly as I said them*". Read the five number sequence at a rate of one digit per second.

Backward Digit Span: Administration: Give the following instruction: "*Now I am going to say some more numbers, but when I am through you must repeat them to me in the backwards order.*" Read the three number sequence at a rate of one digit per second.

Scoring: Allocate one point for each sequence correctly repeated, (*N.B.*: the correct response for the backwards trial is 2-4-7).

Vigilance: Administration: The examiner reads the list of letters at a rate of one per second, after giving the following instruction: "*I am going to read a sequence of letters. Every time I say the letter A, tap your hand once. If I say a different letter, do not tap your hand*".

Scoring: Give one point if there is zero to one errors (an error is a tap on a wrong letter or a failure to tap on letter A).

Serial 7s: Administration: The examiner gives the following instruction: *"Now, I will ask you to count by subtracting seven from 100, and then, keep subtracting seven from your answer until I tell you to stop."* Give this instruction twice if necessary.

Scoring: This item is scored out of 3 points. Give no (0) points for no correct subtractions, 1 point for one correction subtraction, 2 points for two-to-three correct subtractions, and 3 points if the participant successfully makes four or five correct subtractions. Count each correct subtraction of 7 beginning at 100. Each subtraction is evaluated independently; that is, if the participant responds with an incorrect number but continues to correctly subtract 7 from it, give a point for each correct subtraction. For example, a participant may respond "92 – 85 – 78 – 71 – 64" where the "92" is incorrect, but all subsequent numbers are subtracted correctly. This is one error and the item would be given a score of 3.

7. Sentence repetition:

Administration: The examiner gives the following instructions: *"I am going to read you a sentence. Repeat it after me, exactly as I say it* [pause]: ***I only know that John is the one to help today."*** Following the response, say: *"Now I am going to read you another sentence. Repeat it after me, exactly as I say it* [pause]: ***The cat always hid under the couch when dogs were in the room."***

Scoring: Allocate 1 point for each sentence correctly repeated. Repetition must be exact. Be alert for errors that are omissions (e.g., omitting "only", "always") and substitutions/additions (e.g., "John is the one who helped today;" substituting "hides" for "hid", altering plurals, etc.).

8. Verbal fluency:

Administration: The examiner gives the following instruction: *"Tell me as many words as you can think of that begin with a certain letter of the alphabet that I will tell you in a moment. You can say any kind of word you want, except for proper nouns (like Bob or Boston), numbers, or words that begin with the same sound but have a different suffix, for example, love, lover, loving. I will tell you to stop after one minute. Are you ready?* [Pause] *Now, tell me as many words as you can think of that begin with the letter F.* [time for 60 sec]. *Stop."*

Scoring: Allocate one point if the subject generates 11 words or more in 60 sec. Record the subject's response in the bottom or side margins.

9. Abstraction:

Administration: The examiner asks the subject to explain what each pair of words has in common, starting with the example: *"Tell me how an orange and a banana are alike"*. If the subject answers in a concrete manner, then say only one additional time: *"Tell me another way in which those items are alike"*. If the subject does not give the appropriate response *(fruit)*, say, *"Yes, and they are also both fruit."* Do not give any additional instructions or clarification. After the practice trial, say: *"Now, tell me how a train and a bicycle are alike"*. Following the response, administer the second trial, saying: *"Now tell me how a ruler and a watch are alike"*. Do not give any additional instructions or prompts.

Scoring: Only the last two item pairs are scored. Give 1 point to each item pair correctly answered. The following responses are acceptable:
Train-bicycle = means of transportation, means of travelling, you take trips in both;
Ruler-watch = measuring instruments, used to measure.
The following responses are **not** acceptable: Train-bicycle = they have wheels; Ruler-watch = they have numbers.

10. Delayed recall:

Administration: The examiner gives the following instruction: *"I read some words to you earlier, which I asked you to remember. Tell me as many of those words as you can remember."* Make a check mark (√) for each of the words correctly recalled spontaneously without any cues, in the allocated space.

Scoring: **Allocate 1 point for each word recalled freely without any cues.**

Optional:
Following the delayed free recall trial, prompt the subject with the semantic category cue provided below for any word not recalled. Make a check mark (√) in the allocated space if the subject remembered the word with the help of a category or multiple-choice cue. Prompt all non-recalled words in this manner. If the subject does not recall the word after the category cue, give him/her a multiple choice trial, using the following example instruction, *"Which of the following words do you think it was, NOSE, FACE, or HAND?"*
Use the following category and/or multiple-choice cues for each word, when appropriate:

FACE:	category cue: part of the body	multiple choice: nose, face, hand
VELVET:	category cue: type of fabric	multiple choice: denim, cotton, velvet
CHURCH:	category cue: type of building	multiple choice: church, school, hospital
DAISY:	category cue: type of flower	multiple choice: rose, daisy, tulip
RED:	category cue: a colour	multiple choice: red, blue, green

Scoring: **No points are allocated for words recalled with a cue.** A cue is used for clinical information purposes only and can give the test interpreter additional information about the type of memory disorder. For memory deficits due to retrieval failures, performance can be improved with a cue. For memory deficits due to encoding failures, performance does not improve with a cue.

11. Orientation:

Administration: The examiner gives the following instructions: "Tell me the date today". If the subject does not give a complete answer, then prompt accordingly by saying: *"Tell me the [year, month, exact date, and day of the week]."* Then say: *"Now, tell me the name of this place, and which city it is in."*

Scoring: Give one point for each item correctly answered. The subject must tell the exact date and the exact place (name of hospital, clinic, office). No points are allocated if subject makes an error of one day for the day and date.

TOTAL SCORE: Sum all subscores listed on the right-hand side. Add one point for an individual who has 12 years or fewer of formal education, for a possible maximum of 30 points. A final total score of 26 and above is considered normal.

Appendix III

Human Ethics Committee Approval

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2012/28

11 April 2012

Bridget Hagar
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Bridget

The Human Ethics Committee advises that your research proposal "Effects of aging and sex on directed and undirected attention dichotic listening tasks" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 5 April 2012.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

Appendix IV

University of Canterbury Information Sheet and Consent Form

Department of Communication Disorders
Project Information Sheet

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

PARTICIPANT INFORMATION

You are invited to participate in the research project entitled *Effects of Aging and Sex on Directed and Undirected Attention Dichotic Listening Tasks.* The aim of this project is to evaluate the effects of listening to speech sounds presented into each ear at the same time and determining which of these sounds is heard most clearly. We are interested in determining whether older adults differ from younger adults and whether males differ from females in their perception of speech sounds.

Your involvement in this project will involve one session, lasting approximately 2 hours, which includes a hearing test, to ensure normal hearing or symmetrical sensorineural hearing loss. In the event that you are found to have hearing levels that fall outside the normal hearing range, a follow up referral to the University of Canterbury Speech and Hearing Clinic will be made and appropriate support will be provided. In addition, in the event that you are found to have a conductive or asymmetrical sensorineural hearing loss you will be unable to participate in the study in which case appropriate follow up and support will be arranged. After completion of the hearing screen you will then be required to listen to various speech sounds presented to both ears simultaneously and indicate what you have heard. You have the right to withdraw from the project at any time without penalty, including withdrawal of any information provided. Withdrawal will not affect any ongoing or future relationship with the University of Canterbury Speech and Hearing Clinic or the Department of Communication Disorders.

The results of the project may be published, and a Masters is a public document, accessible via the University of Canterbury library database but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, the information gathered will be assigned a number and all identifiable information removed. Data will be kept on a hard drive within a lockable room in the Department of Communication Disorders. This data will be kept for five years after which time it will be destroyed.

The project is being carried out as a requirement for a Masters of Audiology by Bridget Hagar under the supervision of Professor Michael Robb. The project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee. If you have any further questions about the research project, please do not hesitate to contact either my supervisor or myself at the University of Canterbury. Thank you once again.

Sincerely,

Bridget Hagar BSLT
Master of Audiology Student
Ph: 3411500
Mob: 027 4656309
Email: bmt47@uclive.ac.nz

Professor Michael Robb
Dept of Communication Disorders
Ph: 364 2987 extn 7077
Email: michael.robb@canterbury.ac.nz

Department of Communication Disorders

Bridget Hagar
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch
19 March 2012

Consent Form

Effects of Aging and Sex on Directed and Undirected Attention Dichotic Listening Tasks

I have read and understood the description of the above-named project. On this basis, I agree to take part as a participant in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided without penalty. I understand that withdrawal will not affect any ongoing or future relationship with the University of Canterbury Speech and Hearing Clinic or the Department of Communication Disorders.

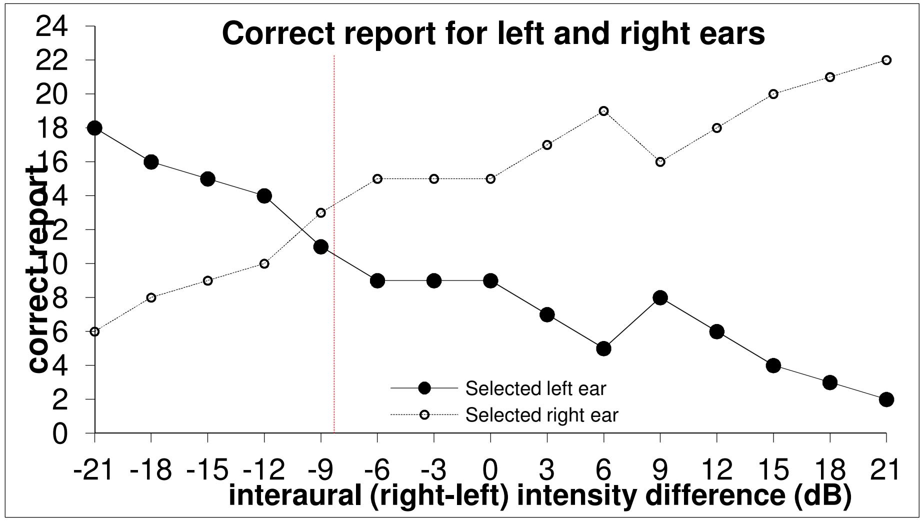
NAME (please print): …………………………………………………………….

Signature:

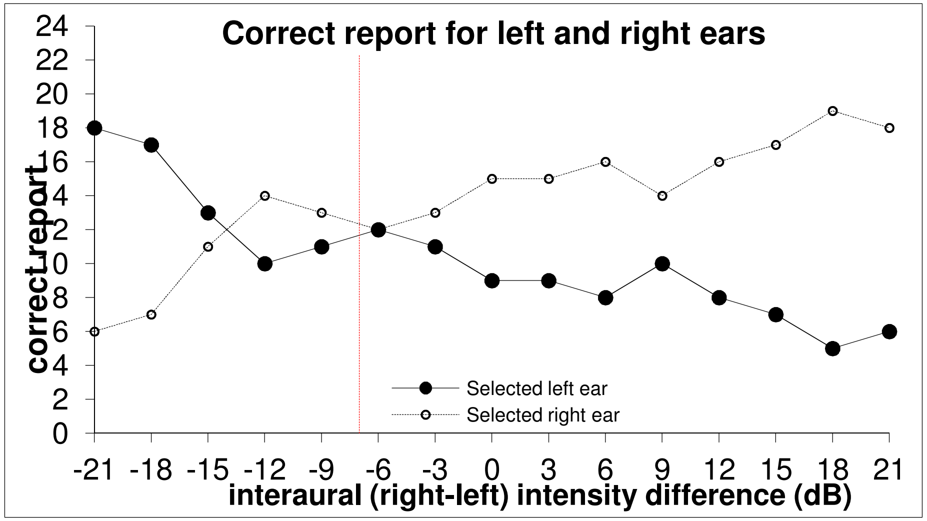
Date:

Appendix V

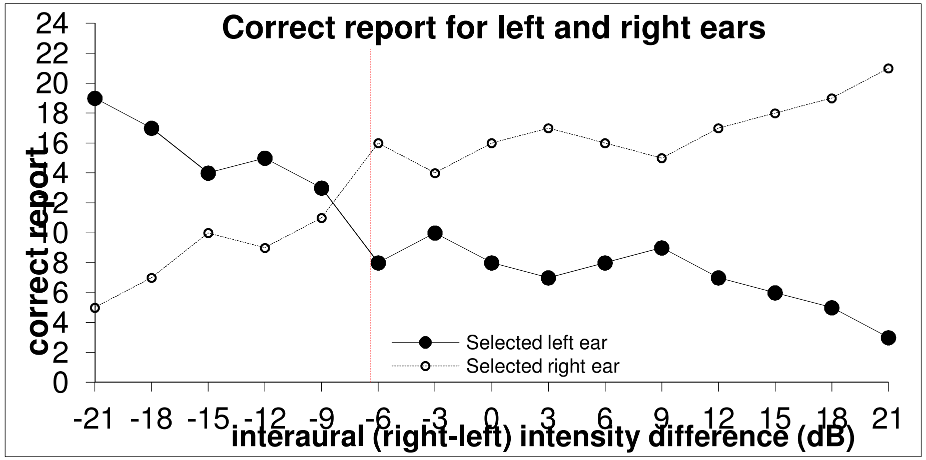
Individual Results of Male Participants in Group 1 (35-44 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



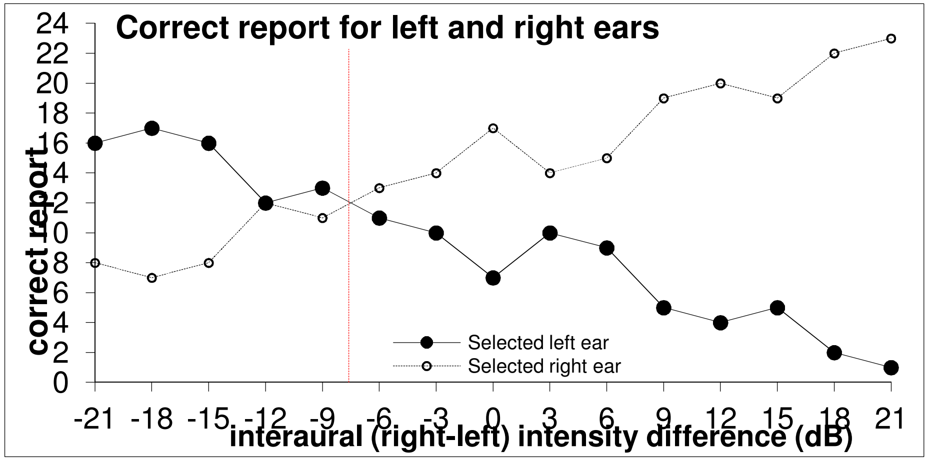
Participant 1



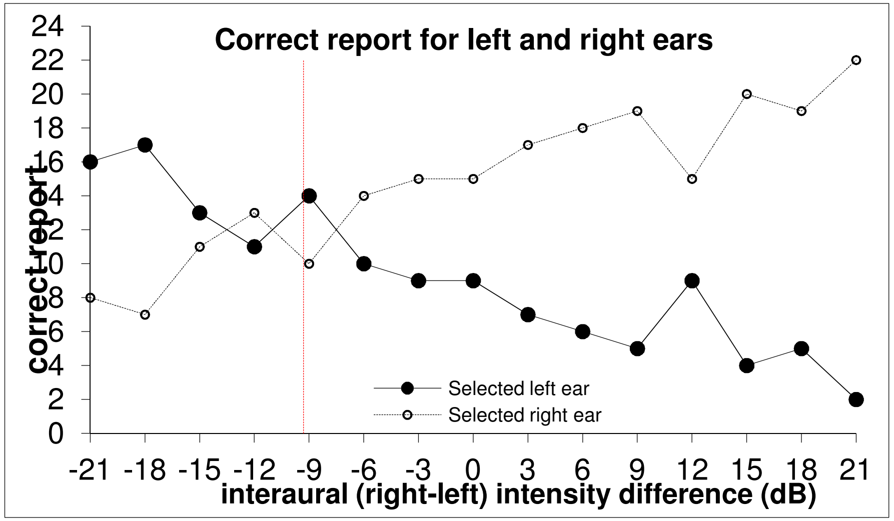
Participant 2



Participant 3



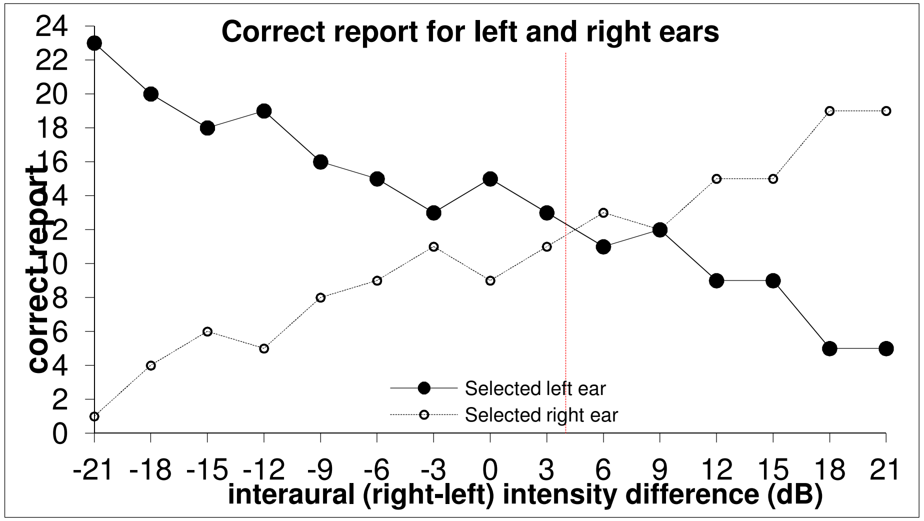
Participant 4



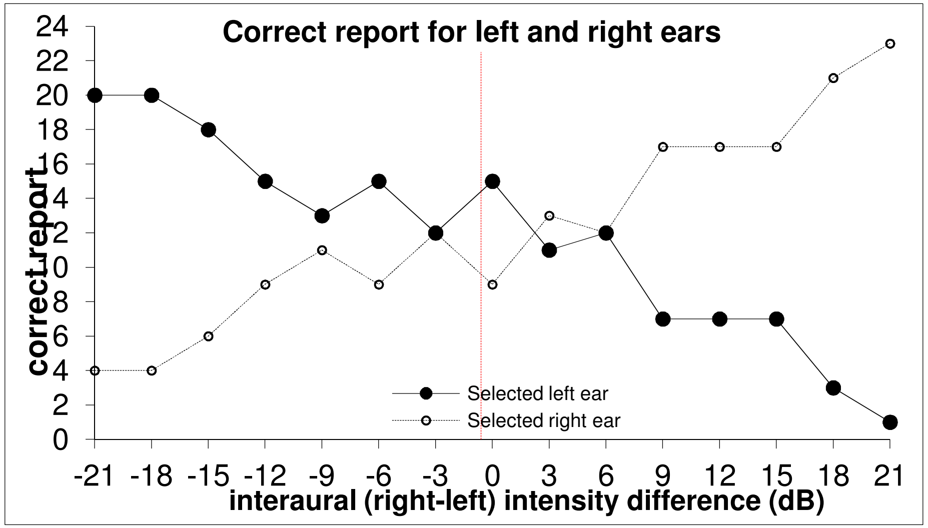
Participant 5

Appendix VI

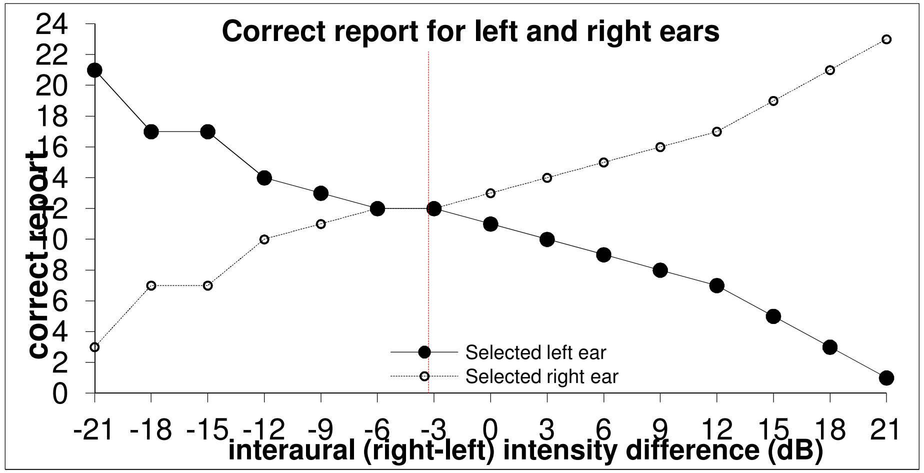
Individual Results of Female Participants in Group 1 (35-44 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



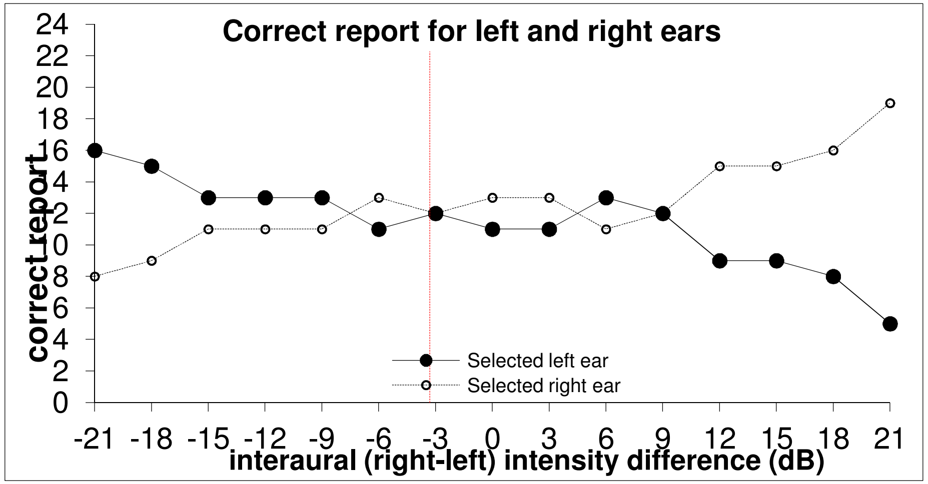
Participant 6



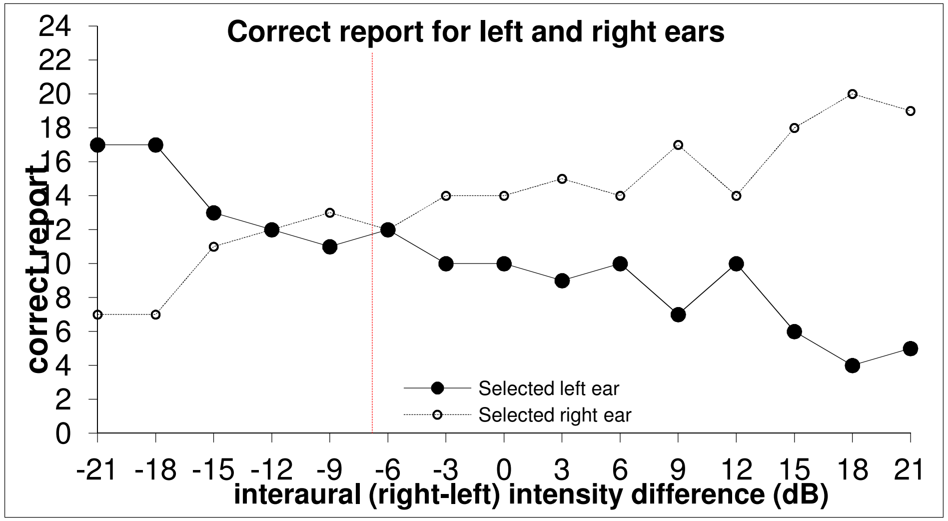
Participant 7



Participant 8



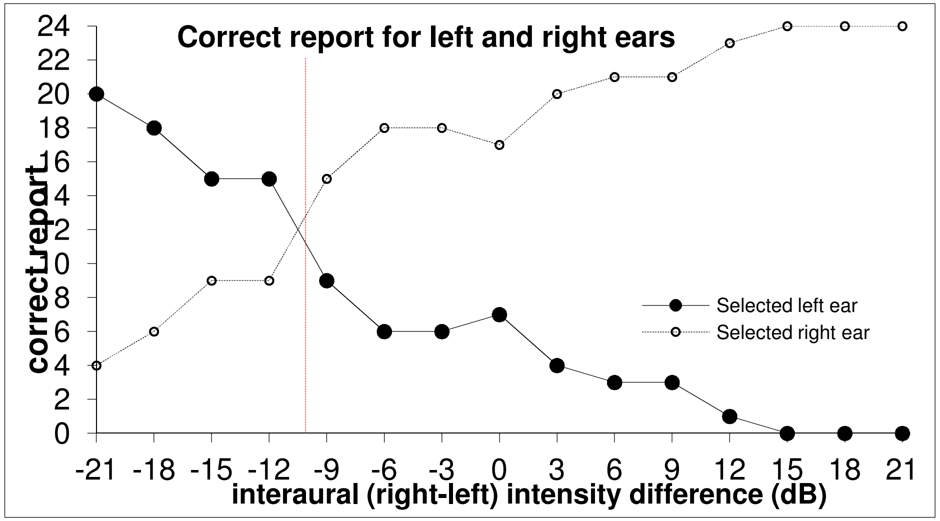
Participant 9



Participant 10

Appendix VII

Individual Results of Male Participants in Group 2 (45-54 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



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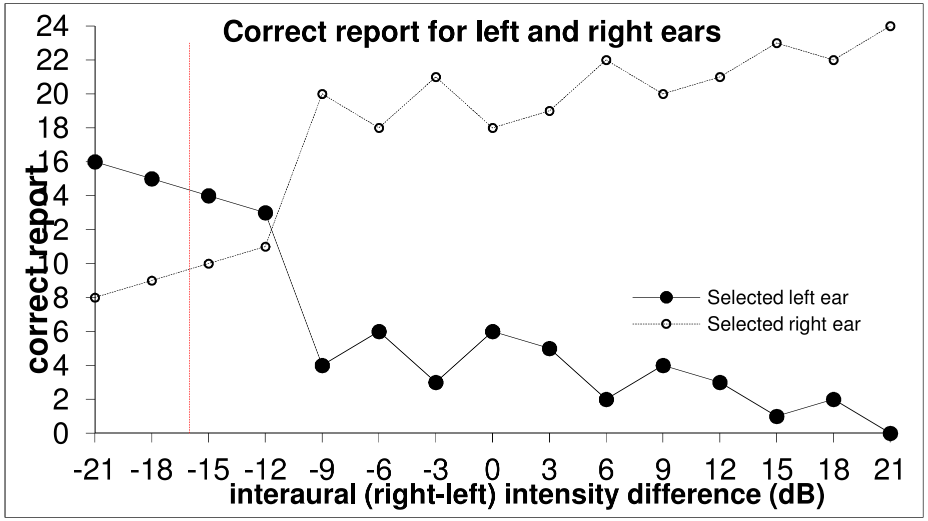
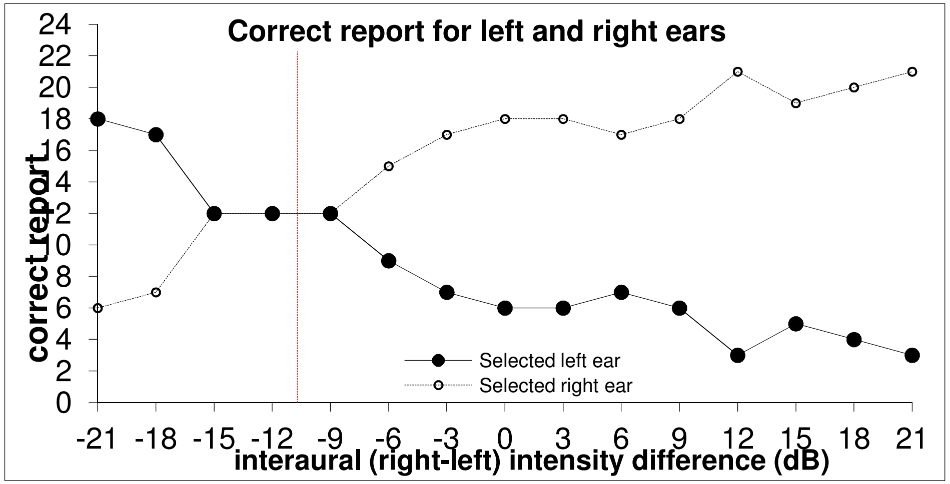
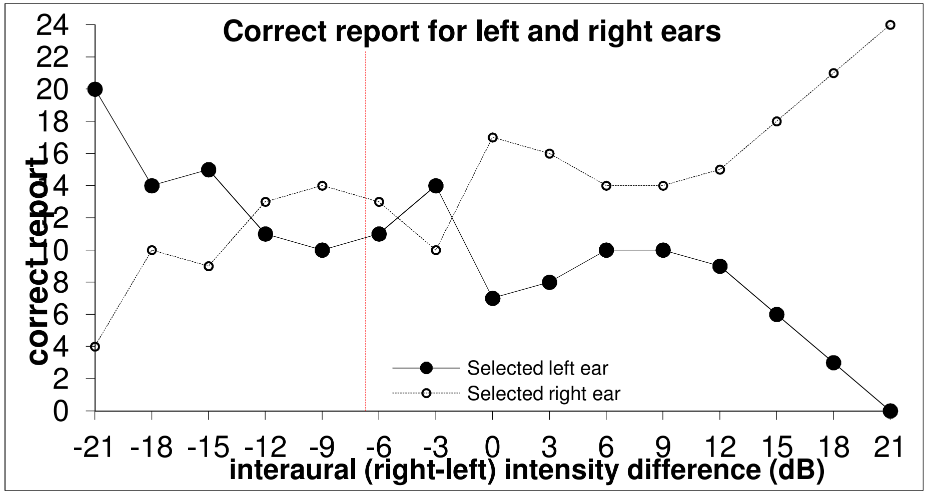


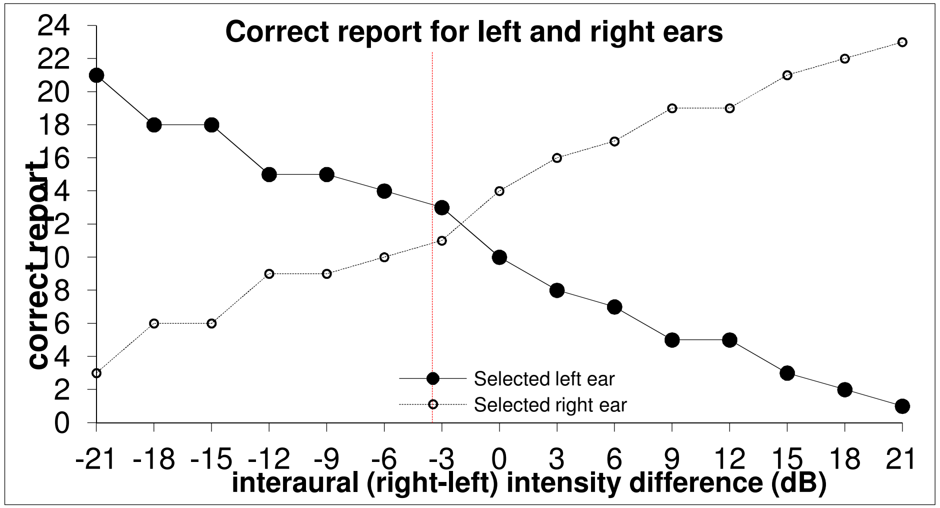
Participant 12



Participant 13



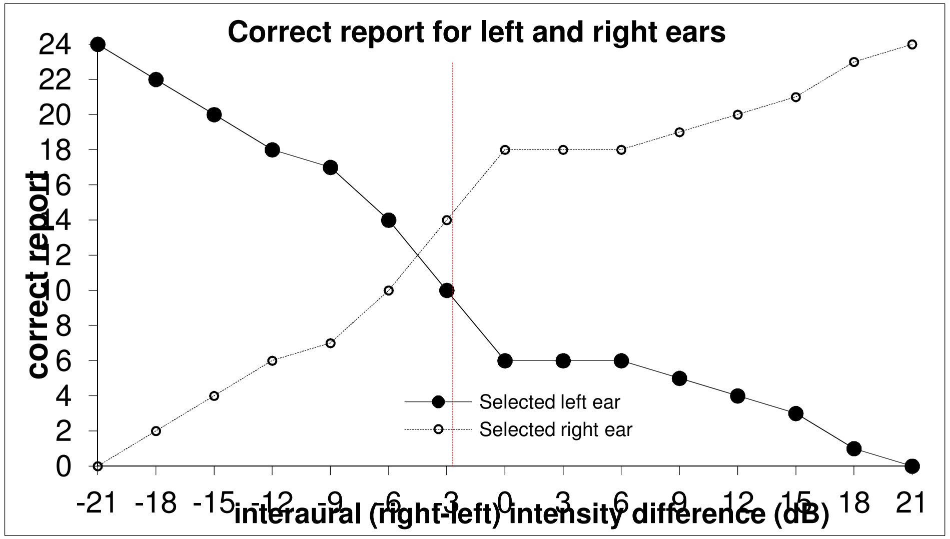
Participant 14



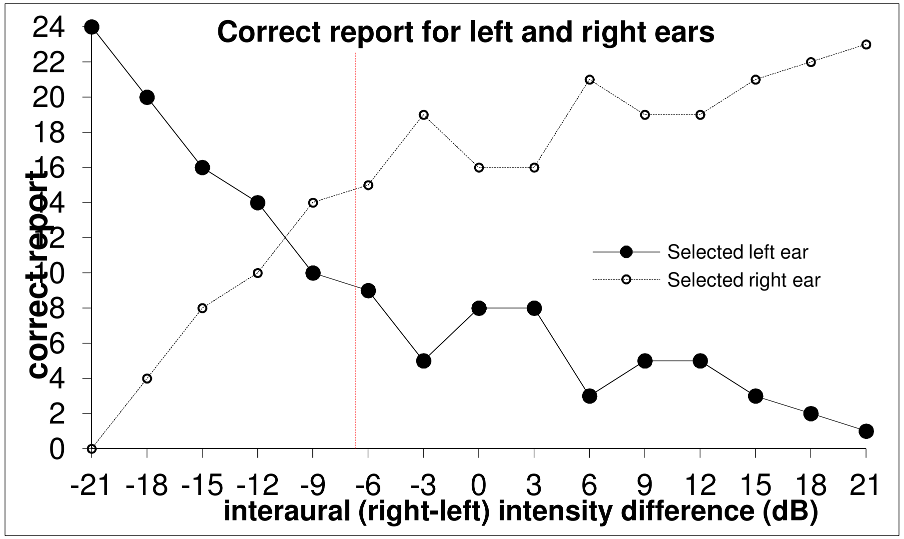
Participant 15

Appendix VIII

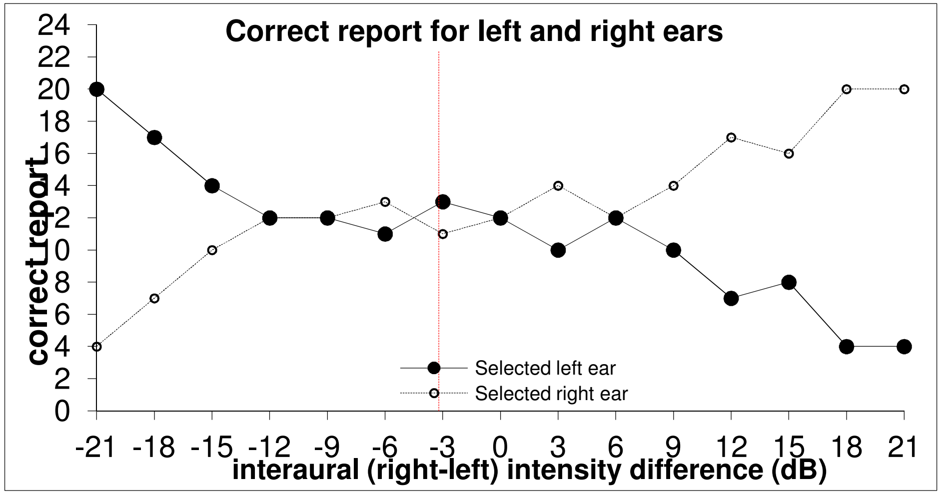
Individual Results of Female Participants in Group 2 (45-54 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



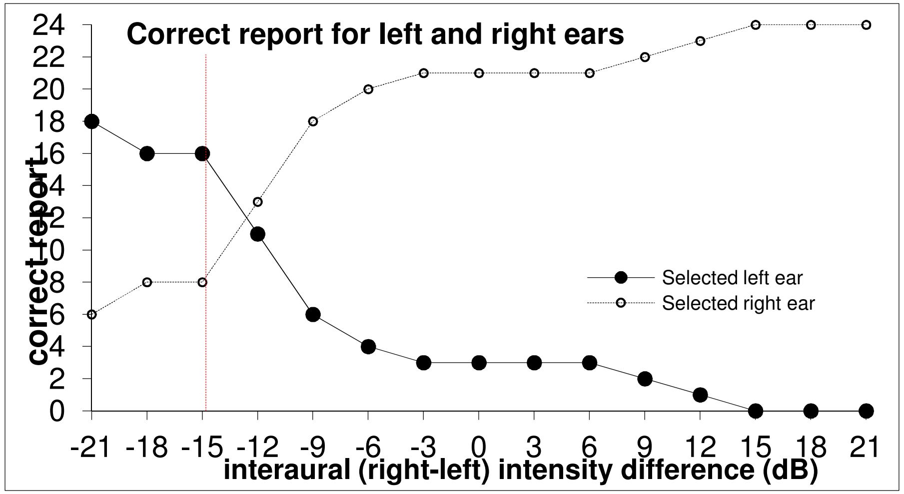
Participant 16



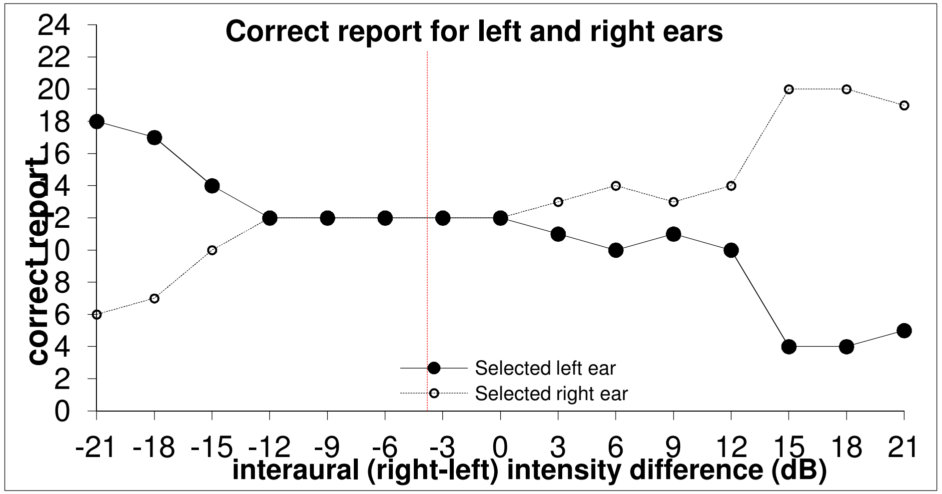
Participant 17



Participant 18



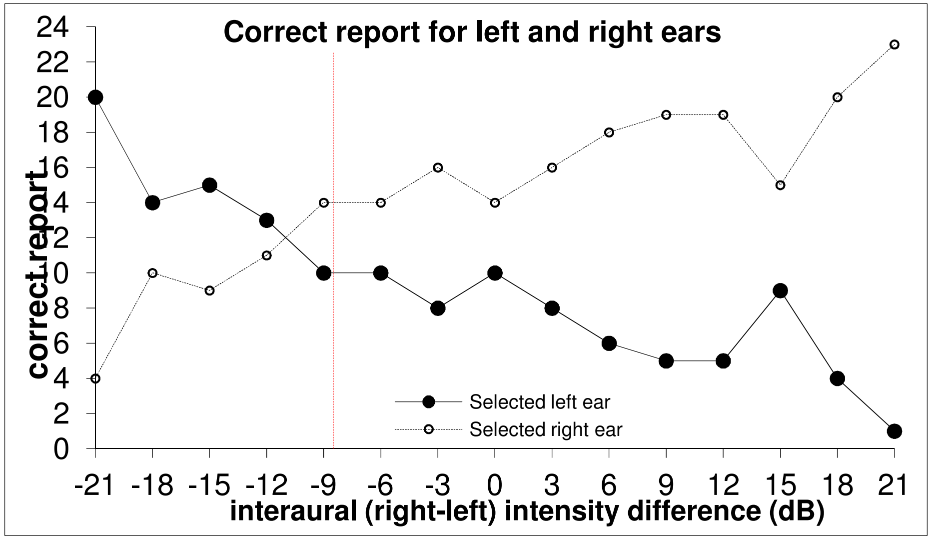
Participant 19



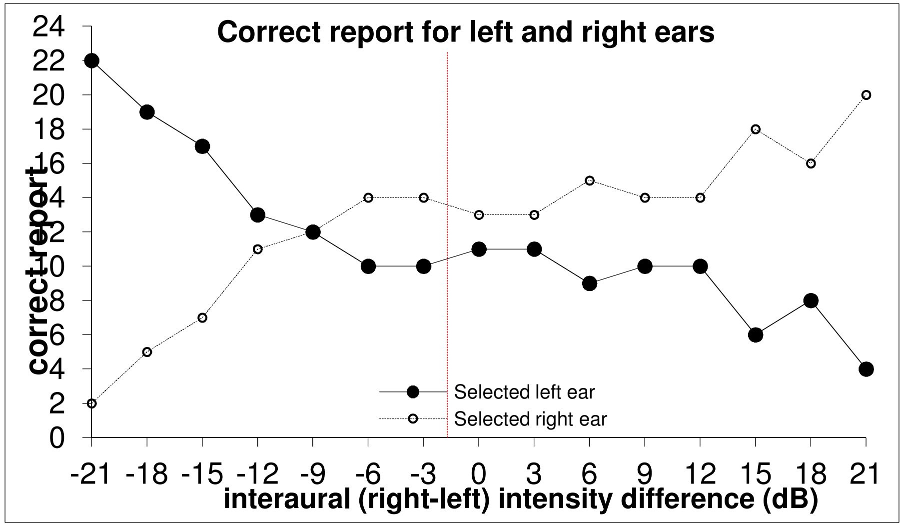
Participant 20

Appendix IX

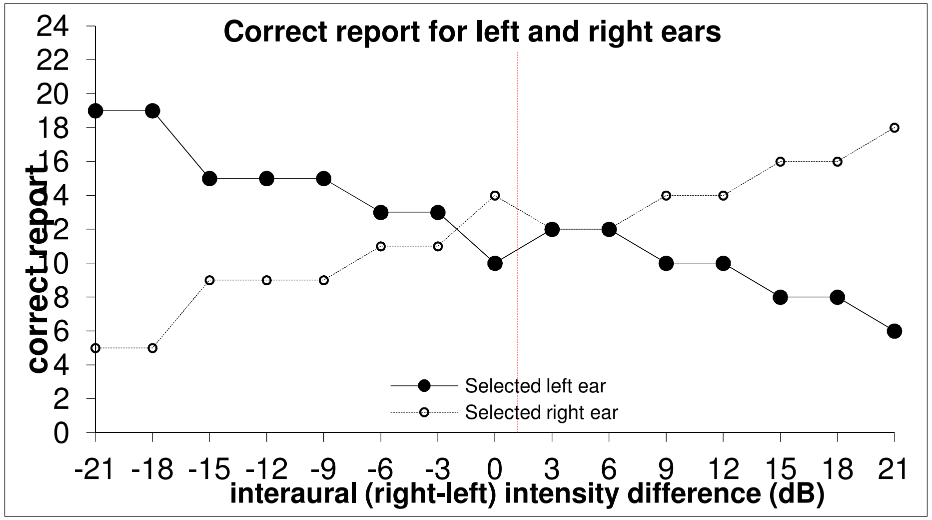
Individual Results of Male Participants in Group 3 (55-64 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



Participant 21



Participant 22



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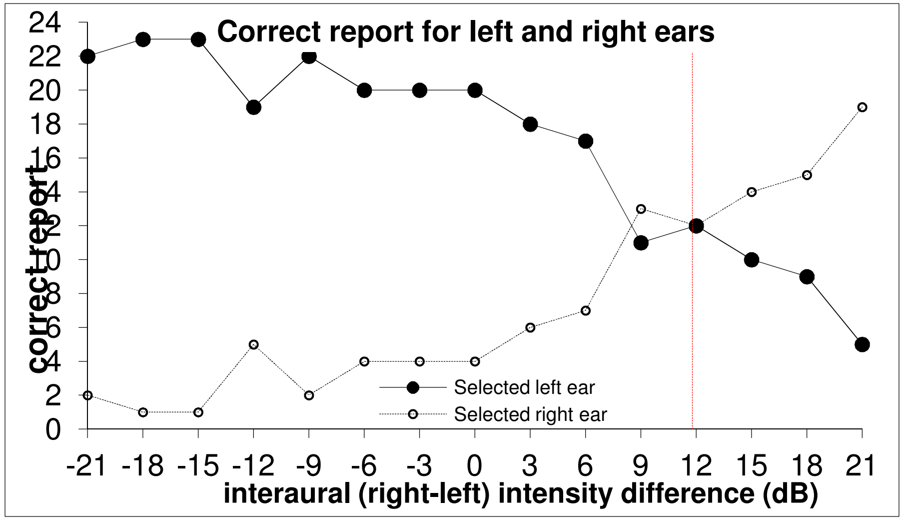

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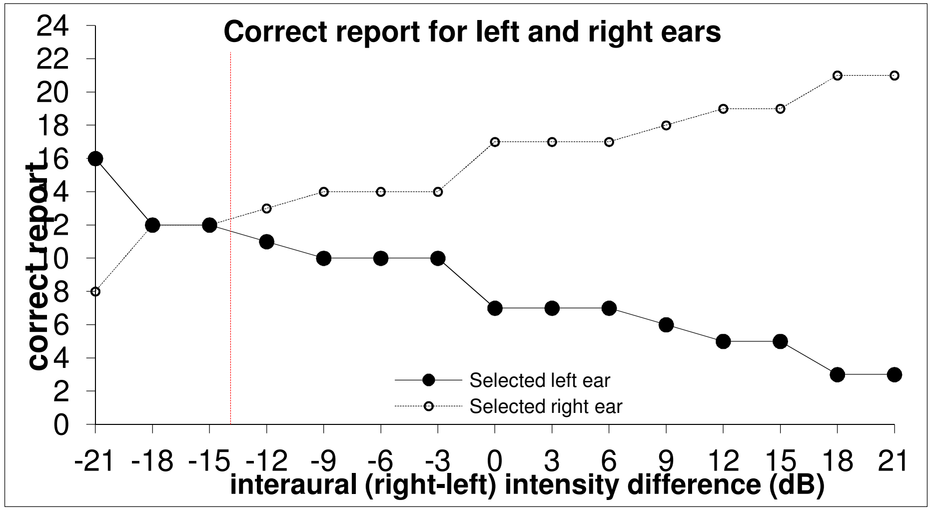
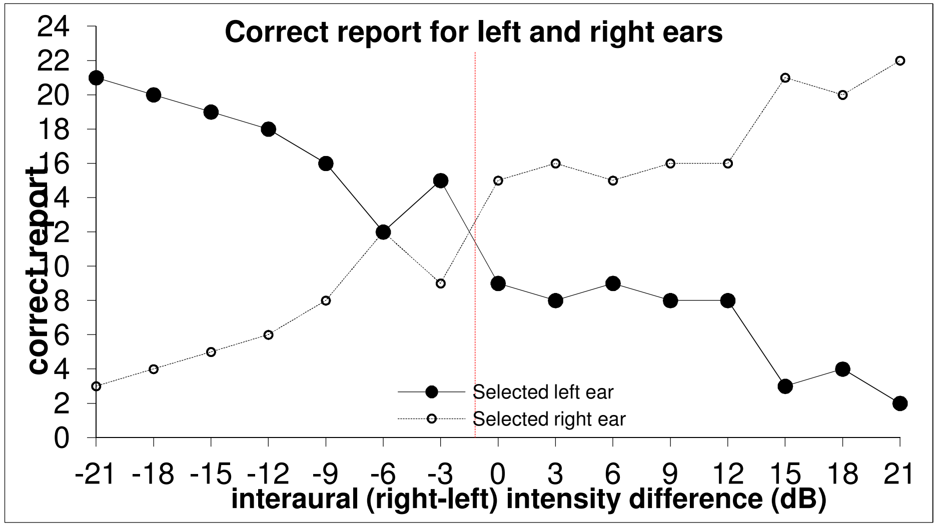


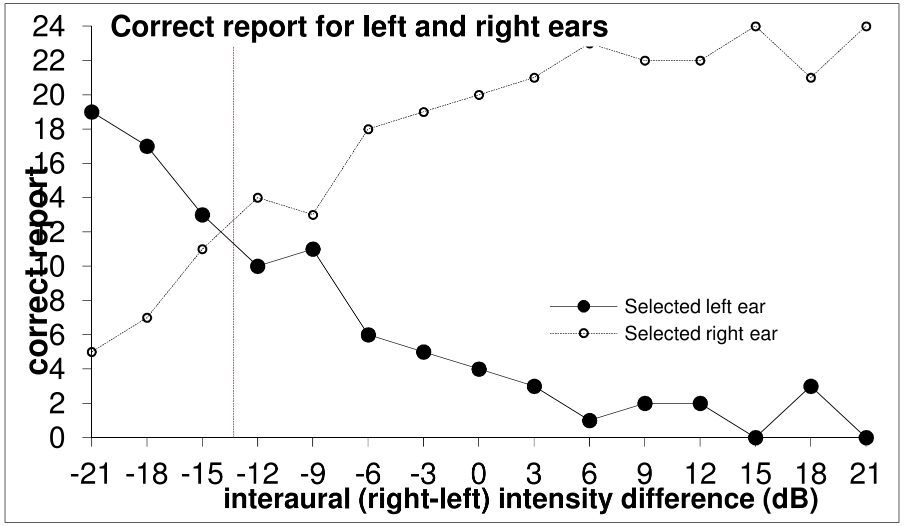
Participant 25

Appendix X

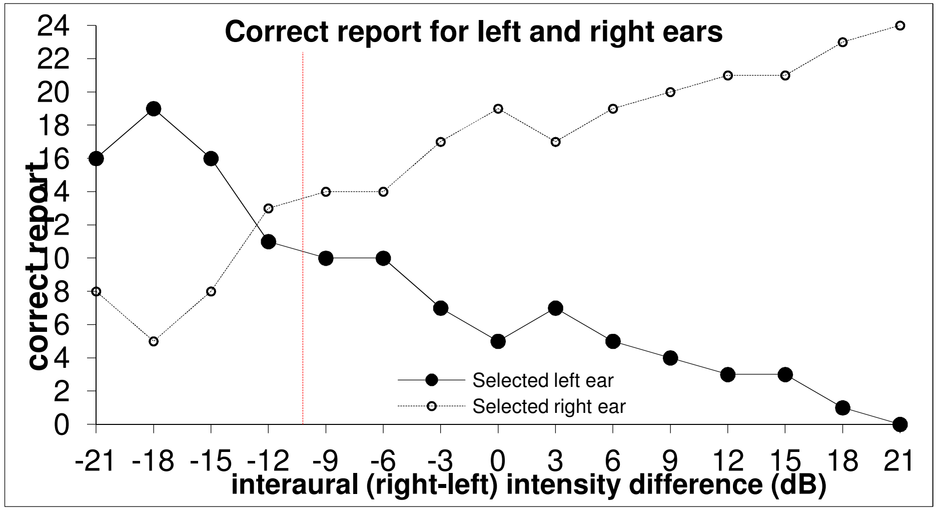
Individual Results of Female Participants in Group 3 (55-64 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



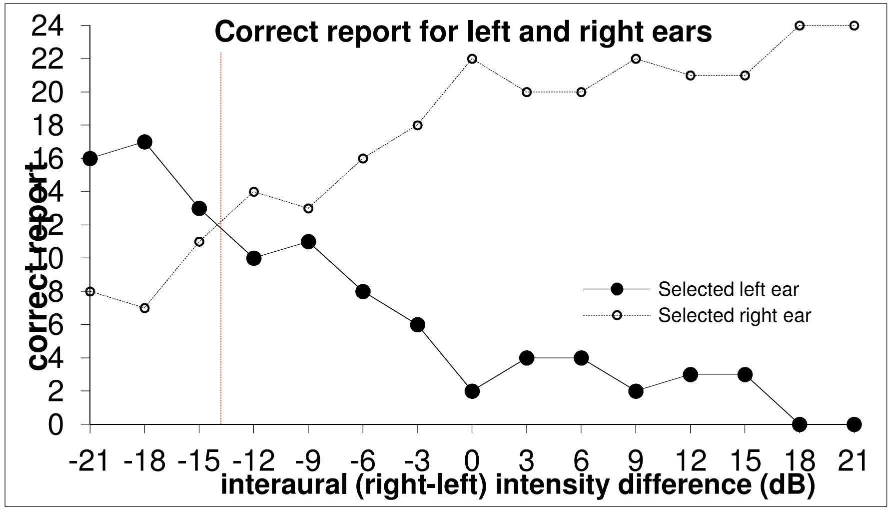
Participant 26



Participant 27



Participant 28



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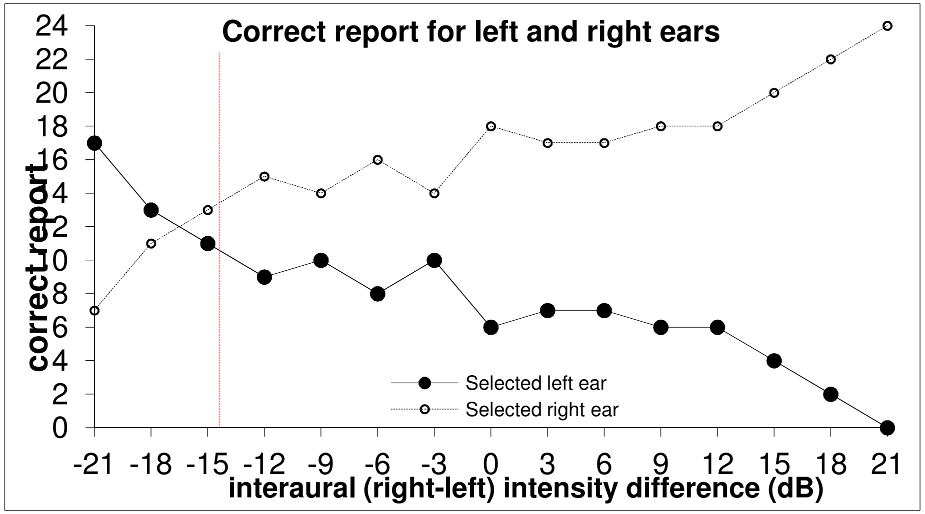
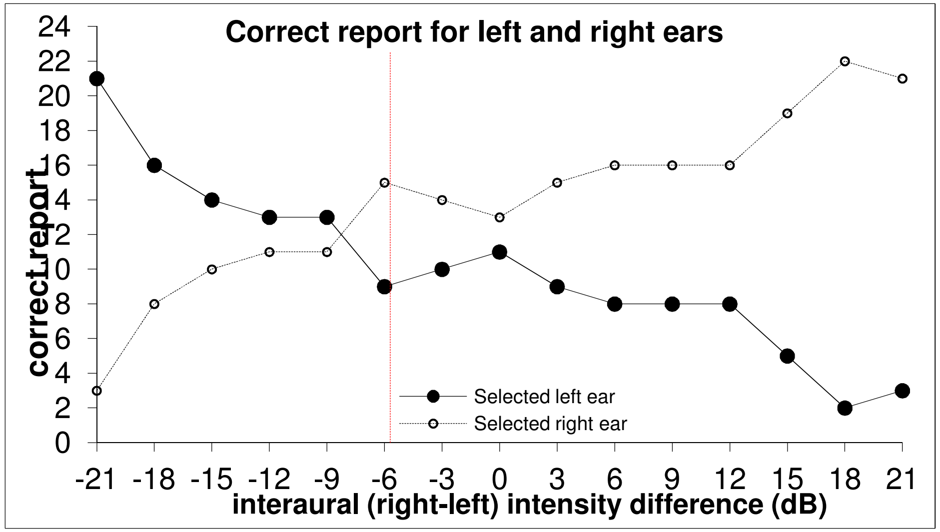


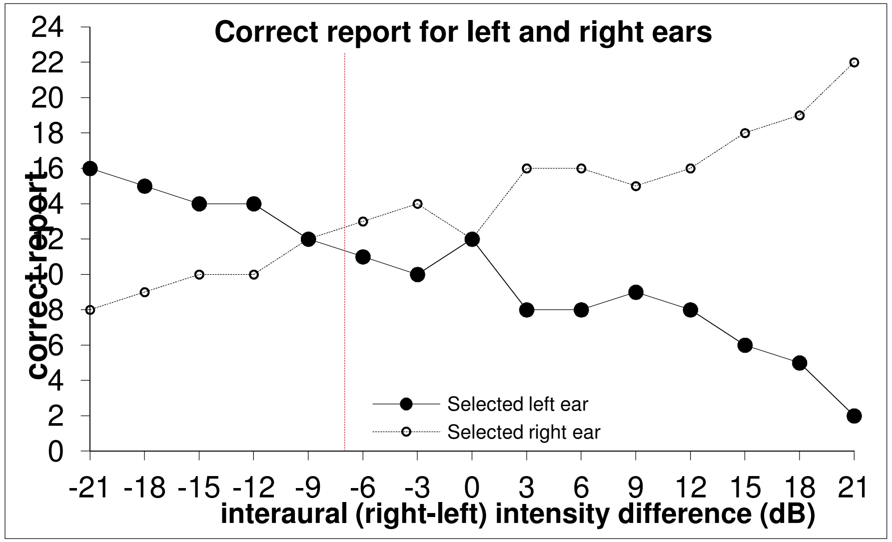
Participant 30

Appendix XI

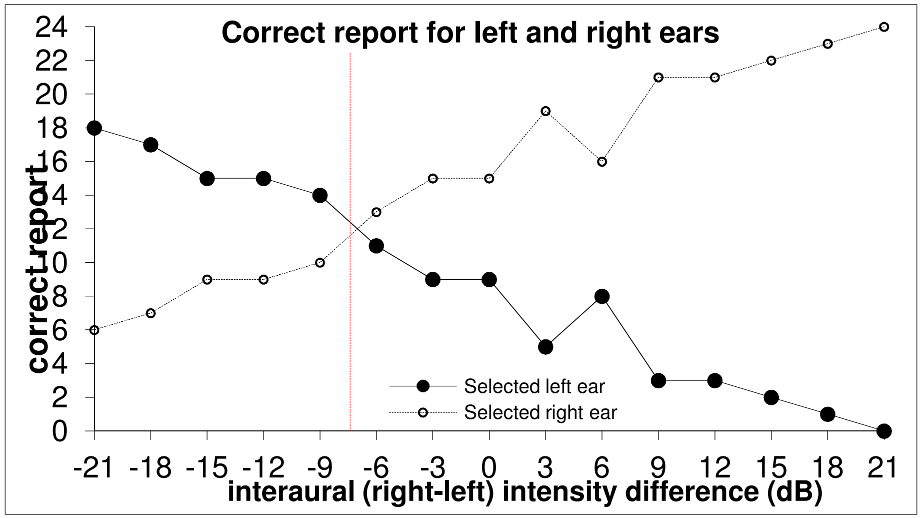
Individual Results of Male Participants in Group 4 (65-74 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



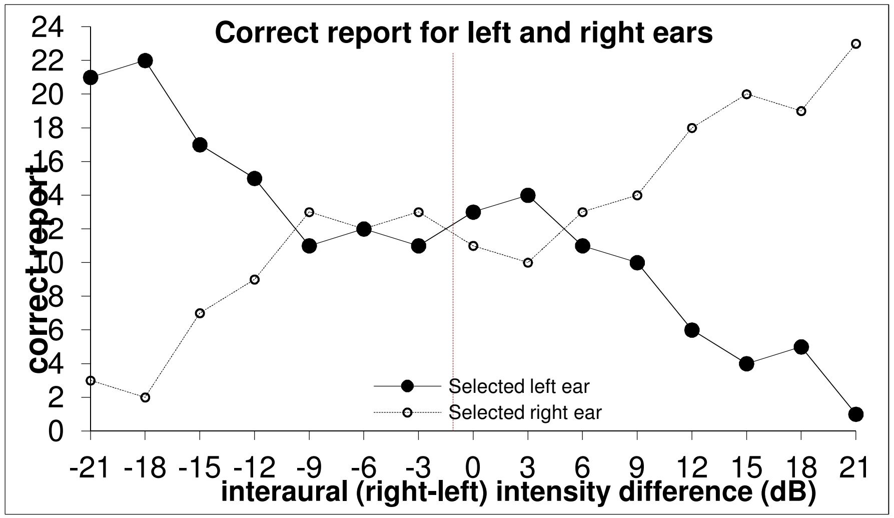
Participant 31



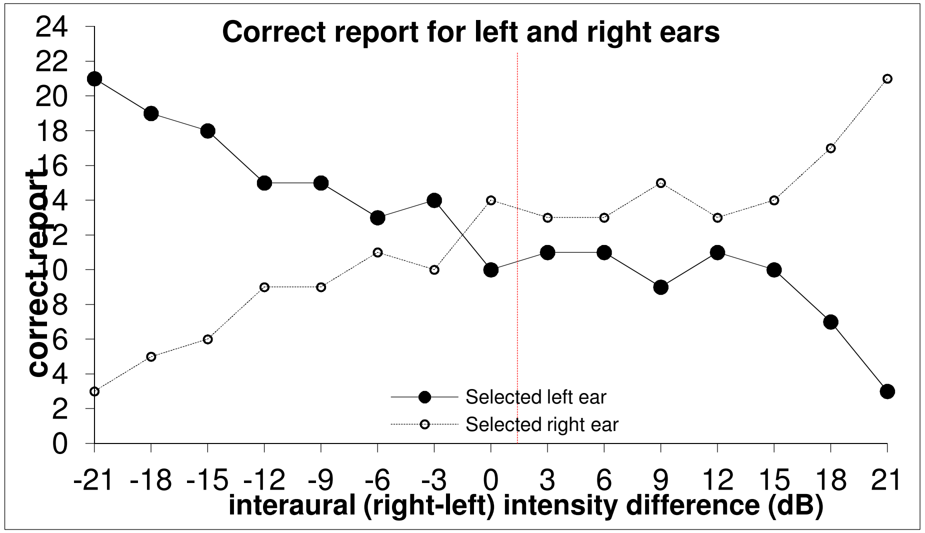
Participant 32



Participant 33



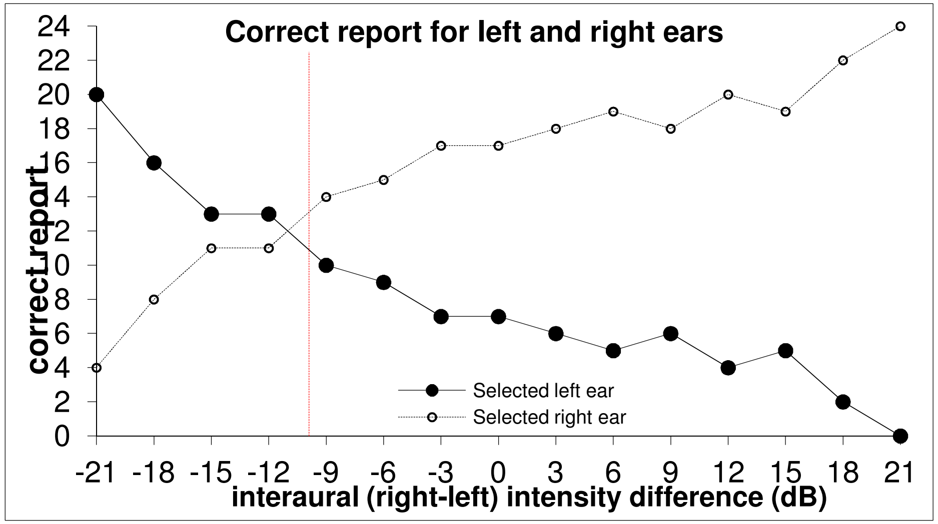
Participant 34



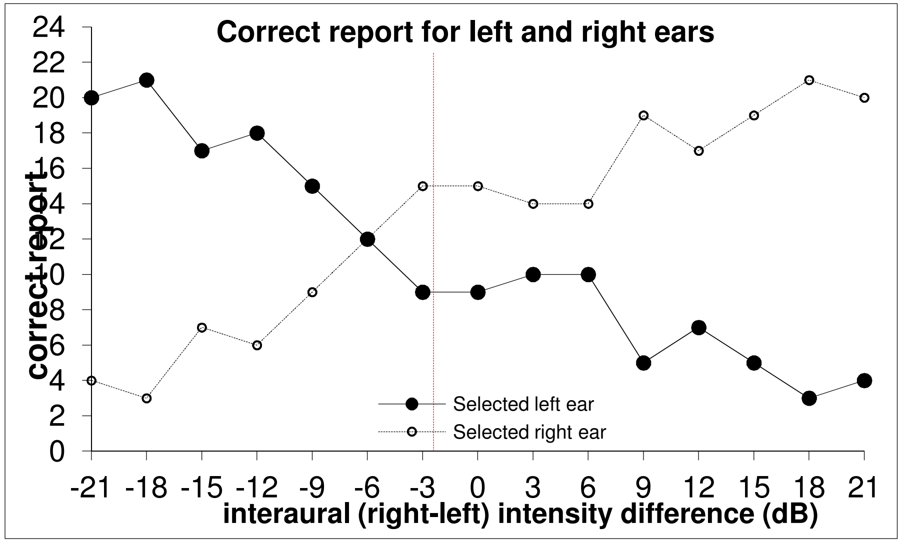
Participant 35

Appendix XII

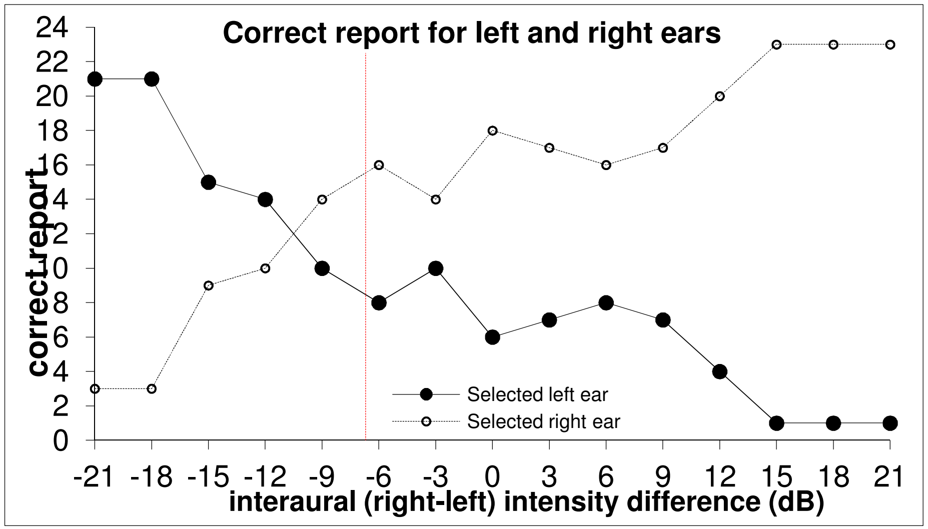
Individual Results of Female Participants in Group 4 (65-74 years) in the Undirected Attention Dichotic Listening Task. Participants are numbered according to Table 1.



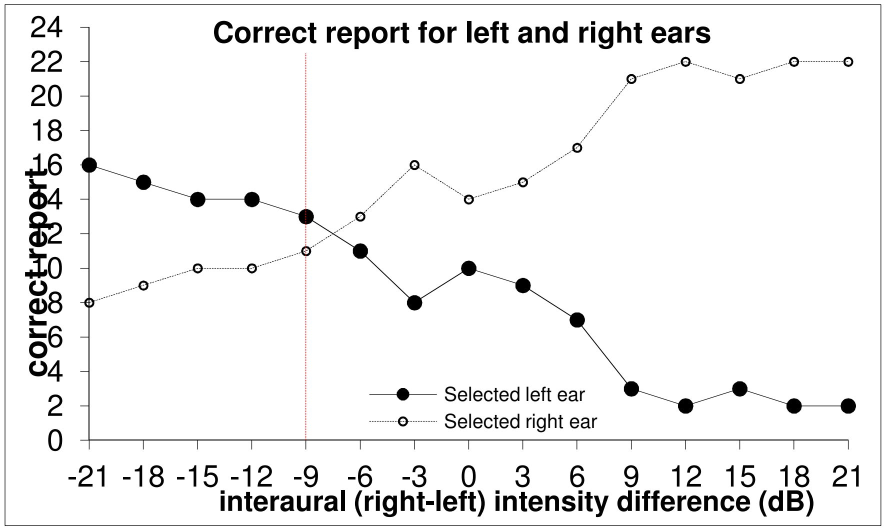
Participant 36



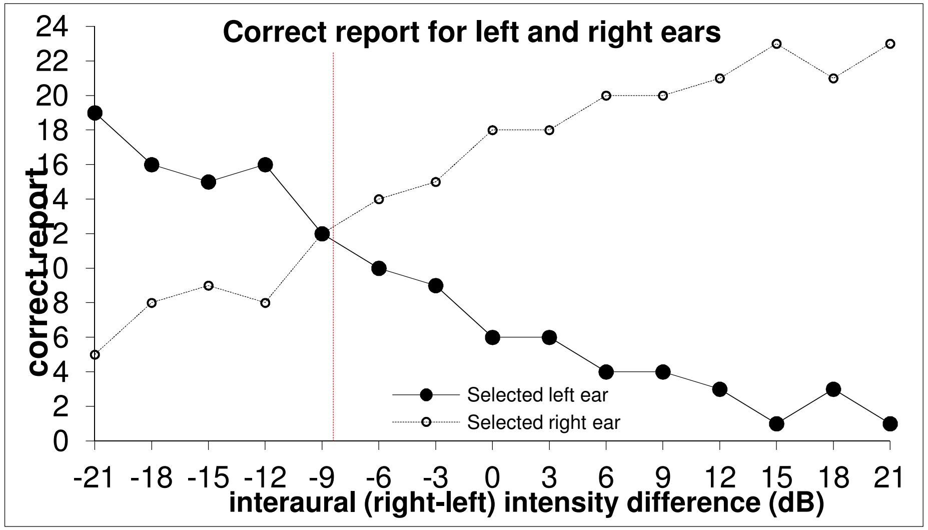
Participant 37



Participant 38



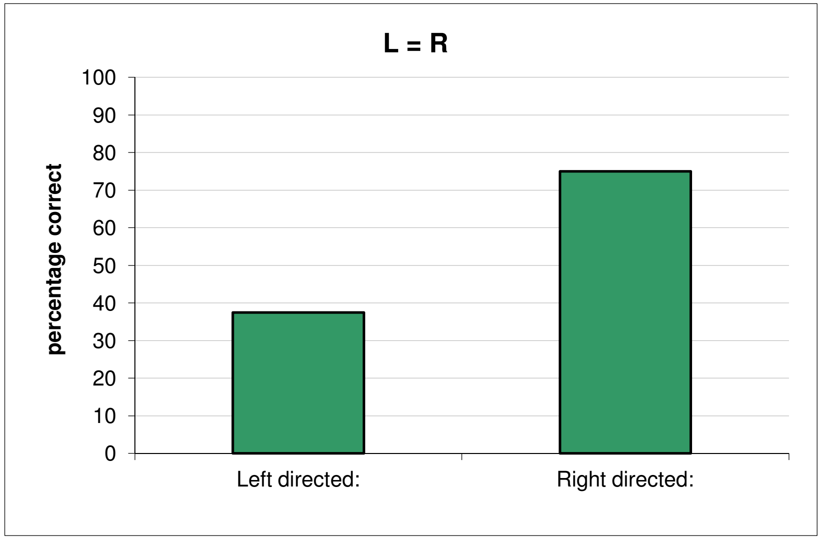
Participant 39



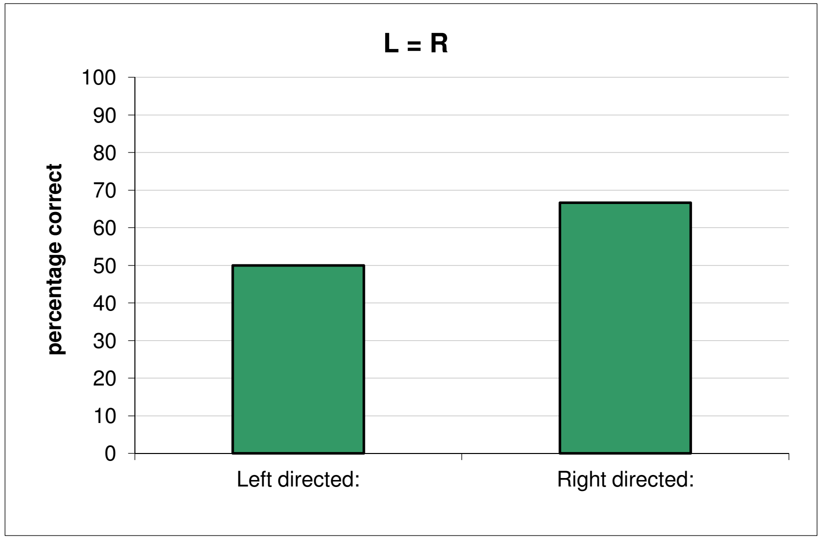
Participant 40

Appendix XIII

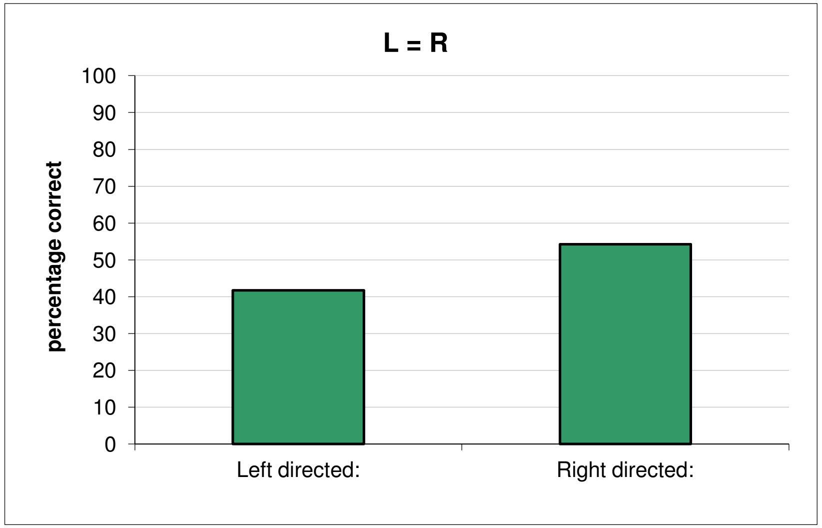
Individual Results of Male Participants in Group 1 (35-44 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



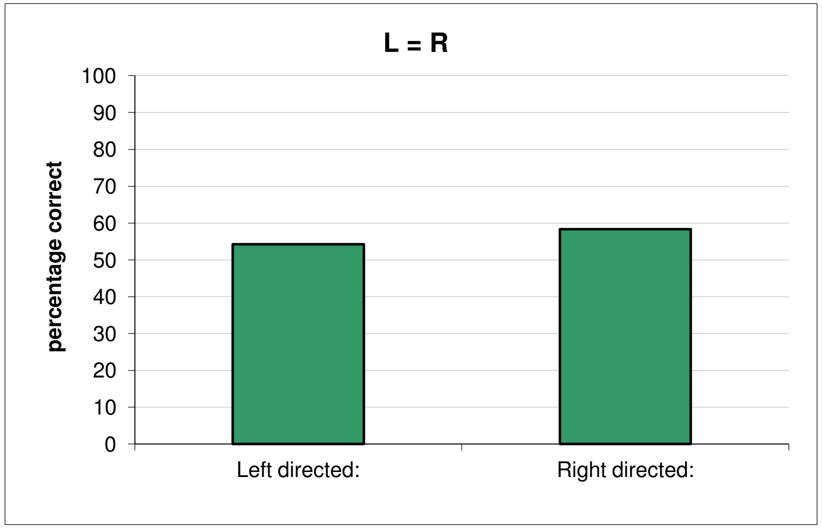
Participant 1



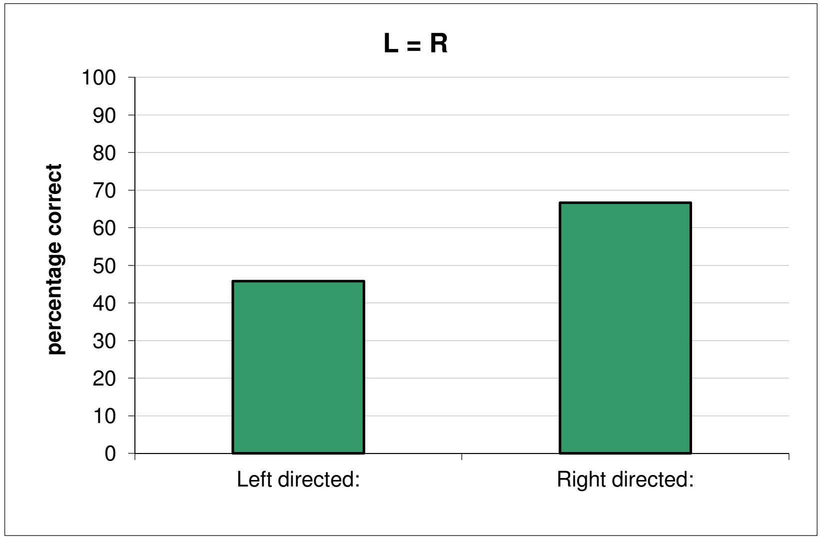
Participant 2



Participant 3



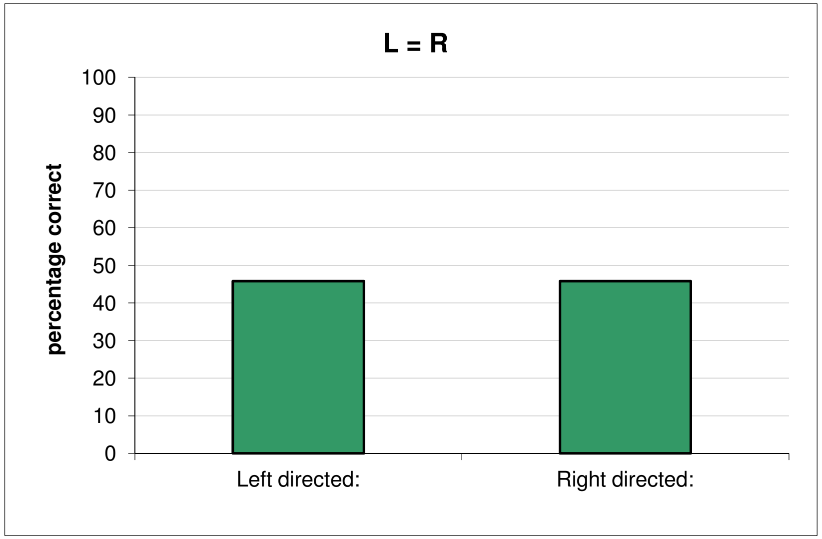
Participant 4



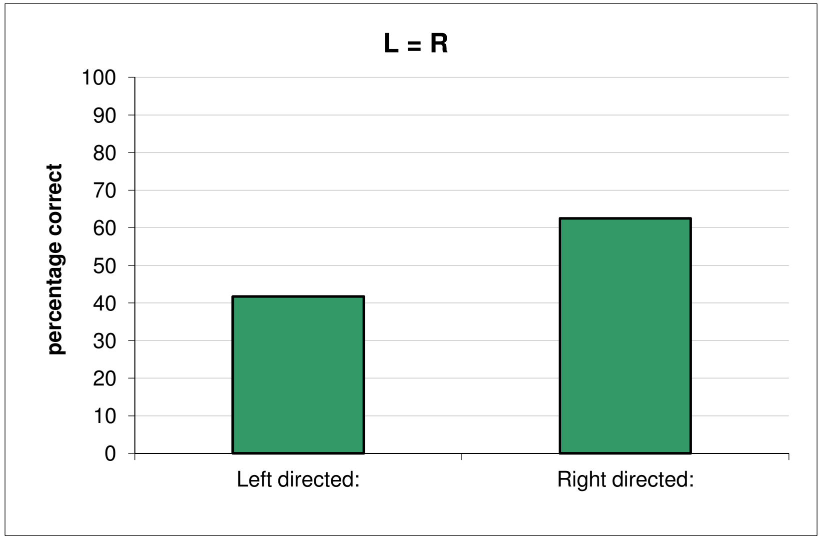
Participant 5

Appendix XIV

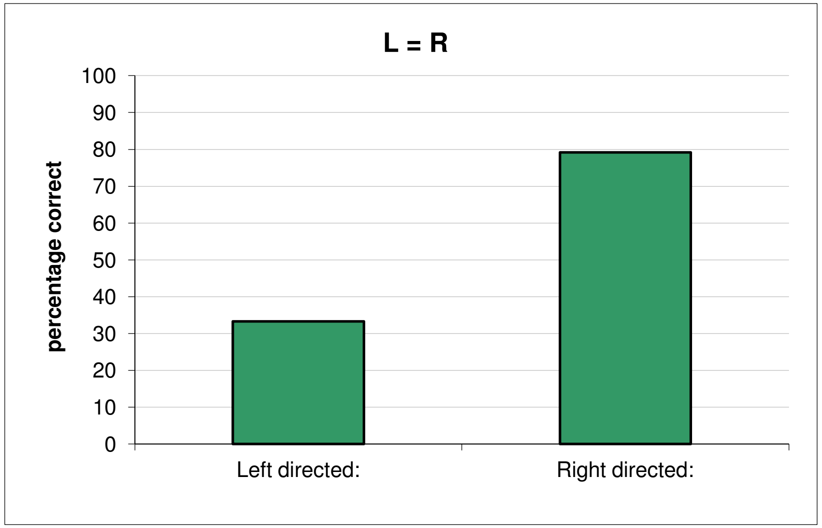
Individual Results of Female Participants in Group 1 (35-44 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



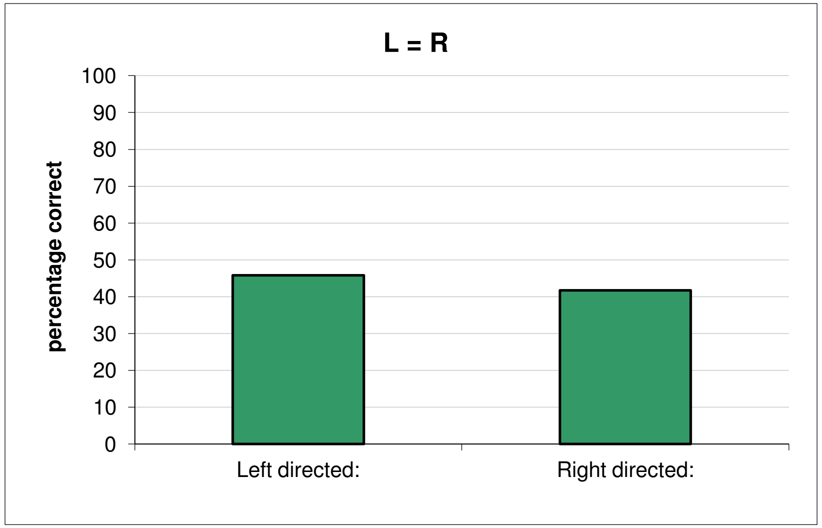
Participant 6



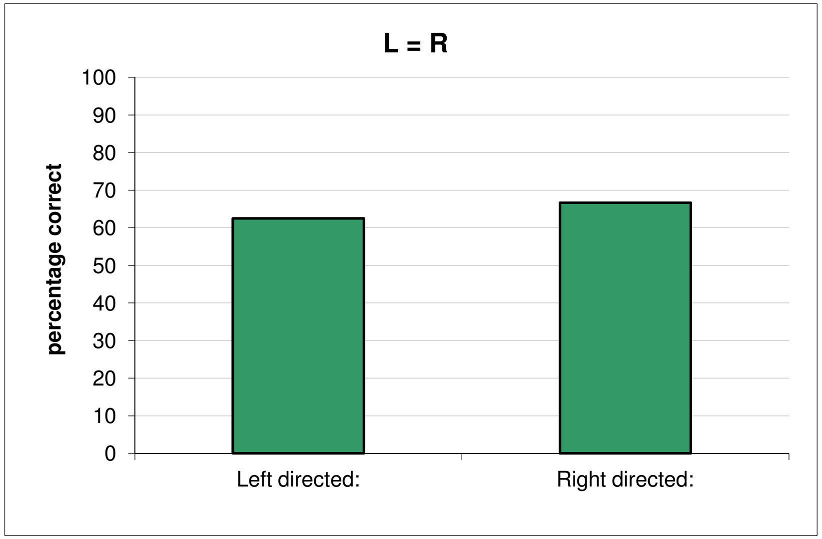
Participant 7



Participant 8



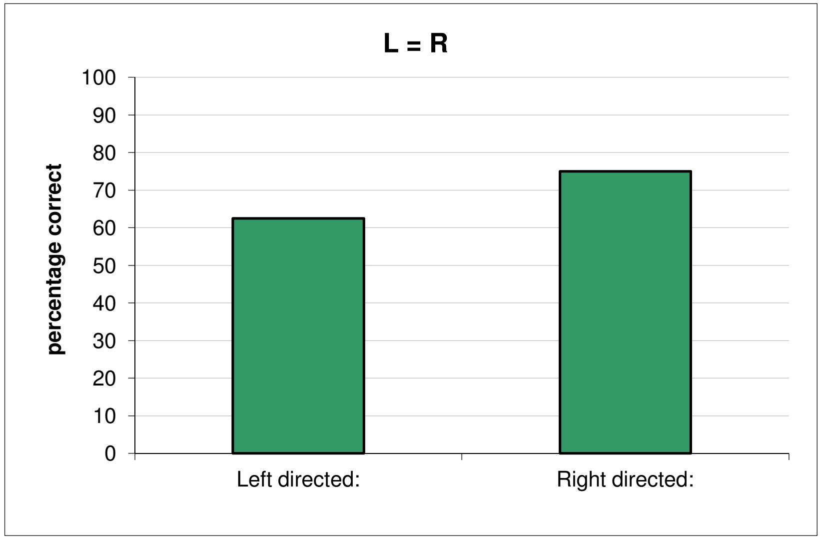
Participant 9



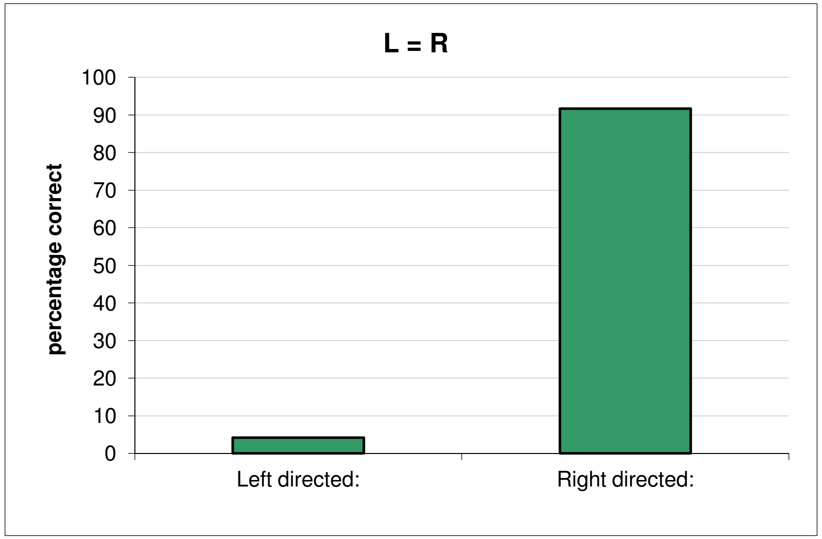
Participant 10

Appendix XV

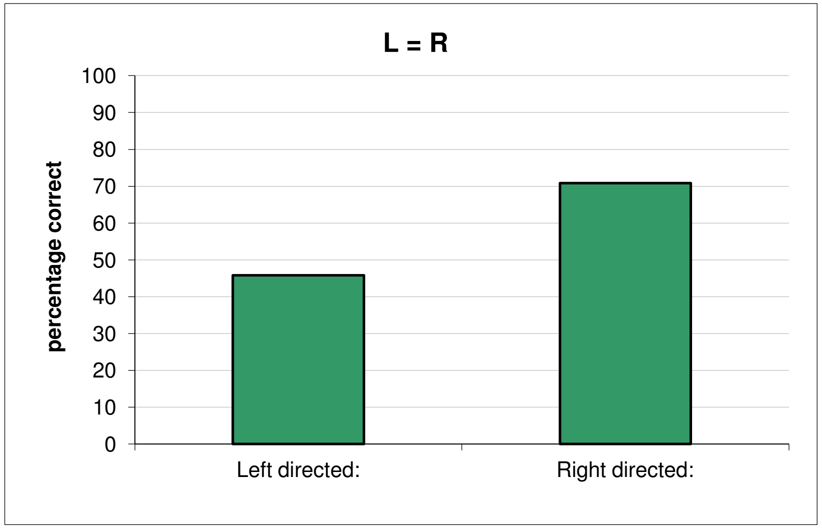
Individual Results of Male Participants in Group 2 (45-54 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



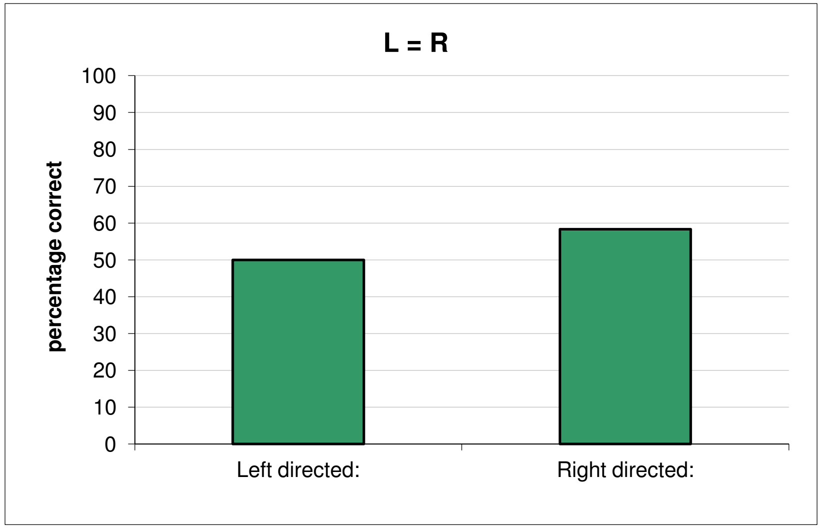
Participant 11



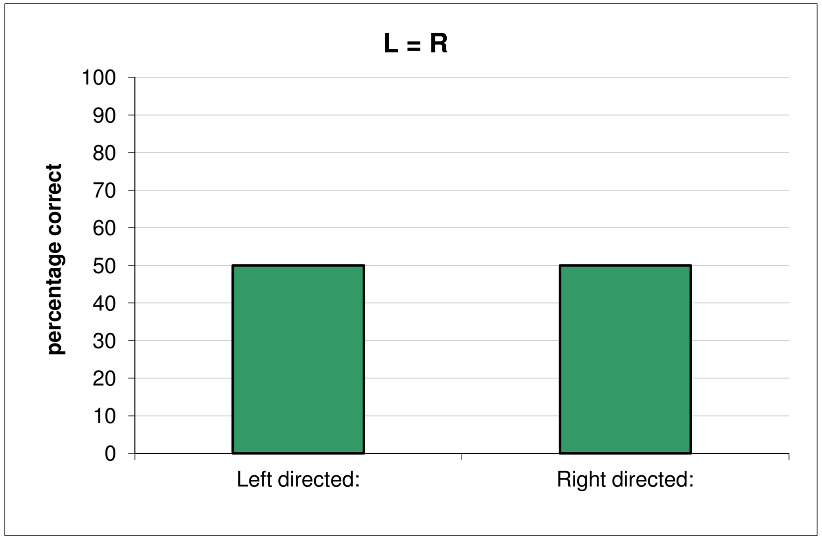
Participant 12



Participant 13



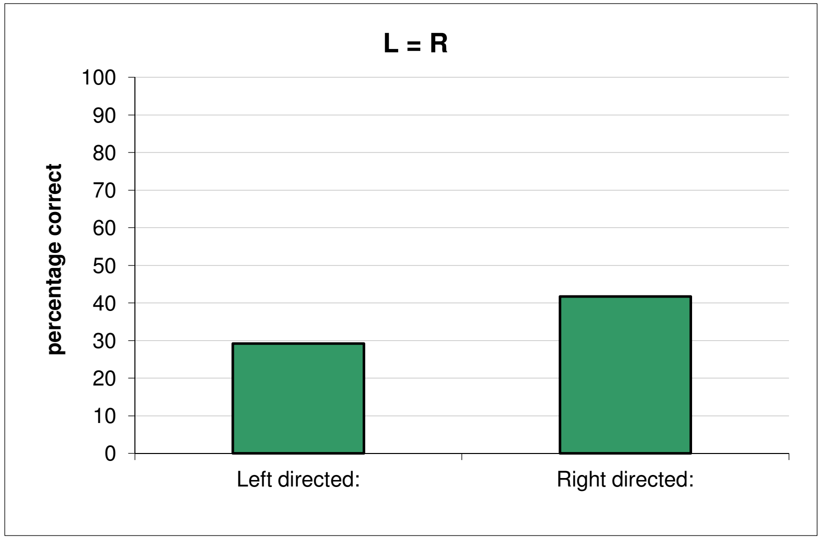
Participant 14



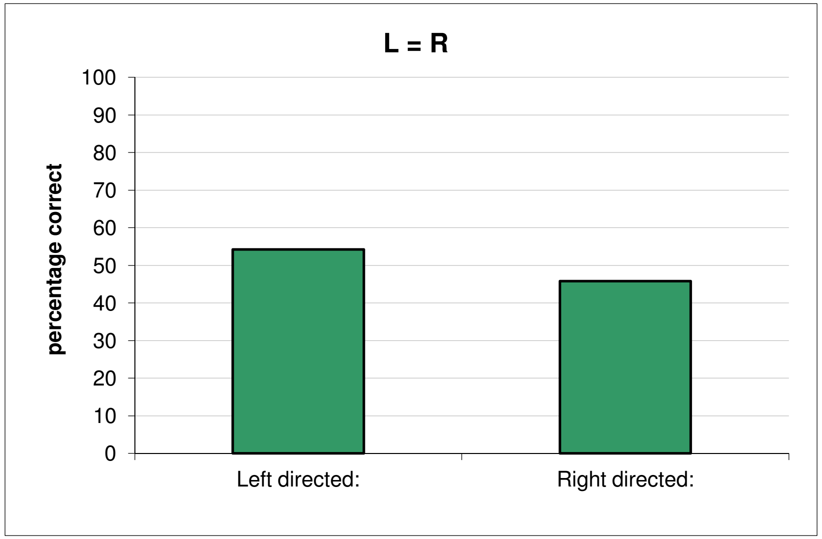
Participant 15

Appendix XVI

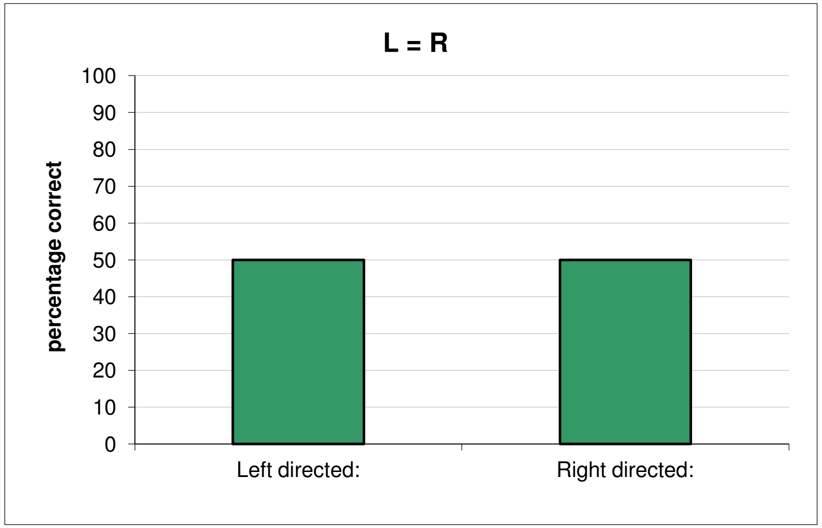
Individual Results of Female Participants in Group 2 (45-54 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



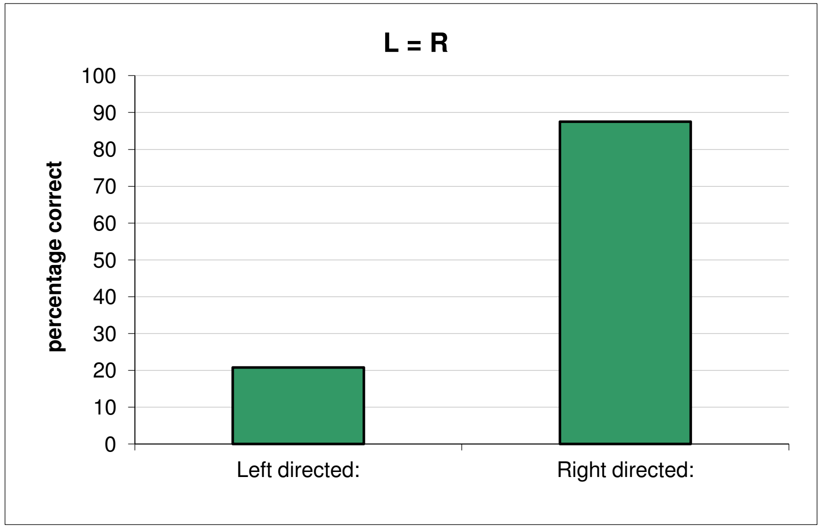
Participant 16



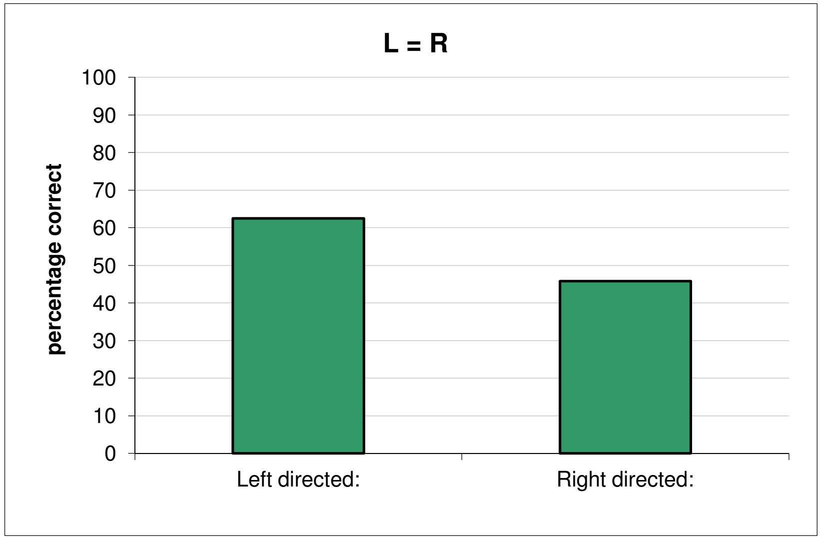
Participant 17



Participant 18



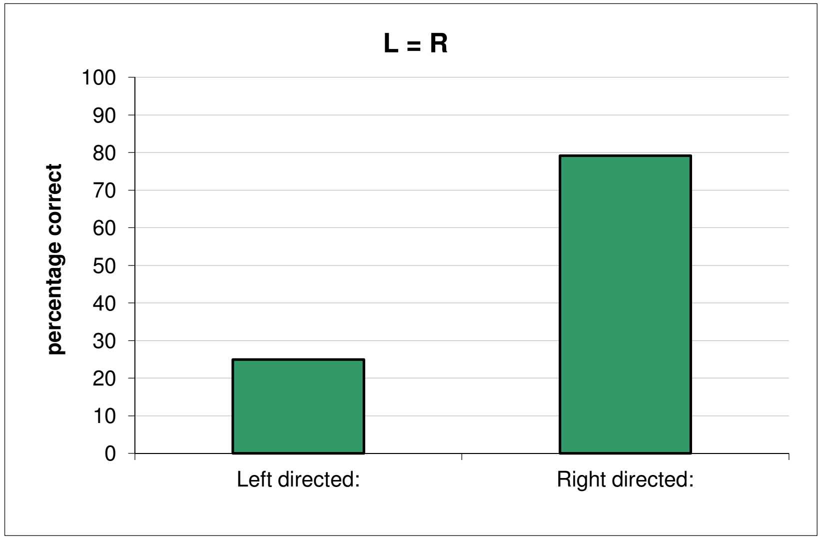
Participant 19



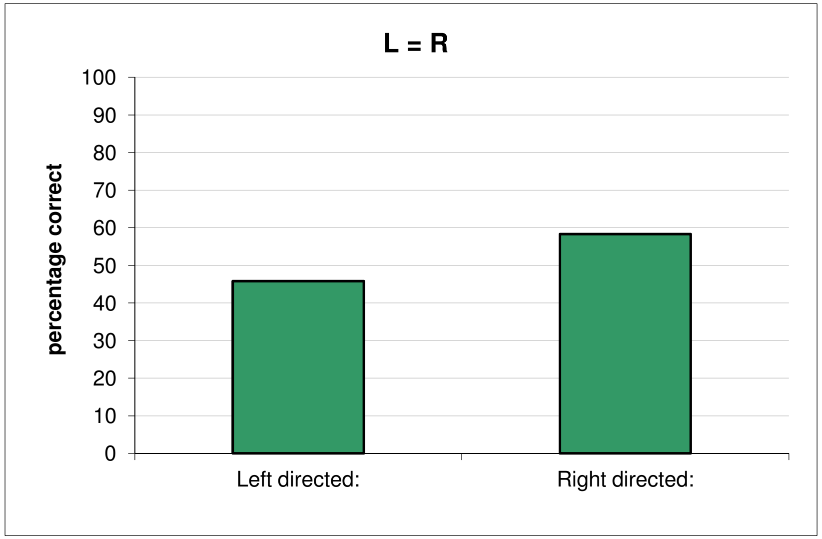
Participant 20

Appendix XVII

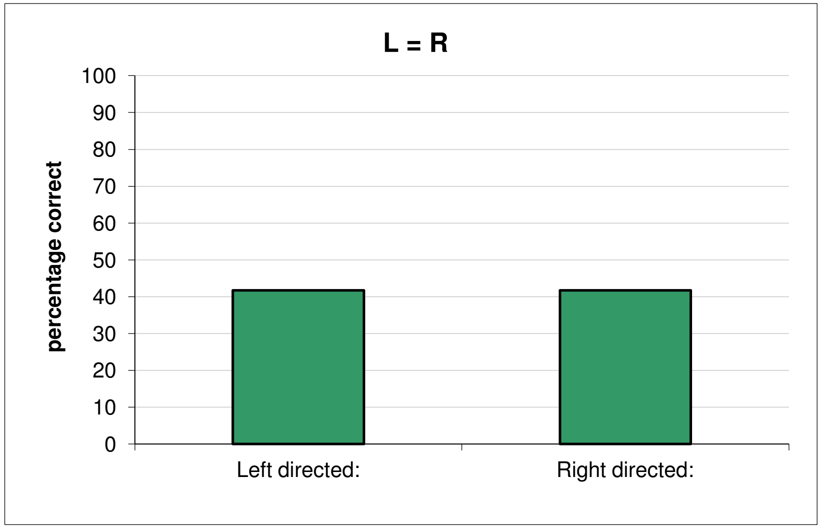
Individual Results of Male Participants in Group 3 (55-64 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



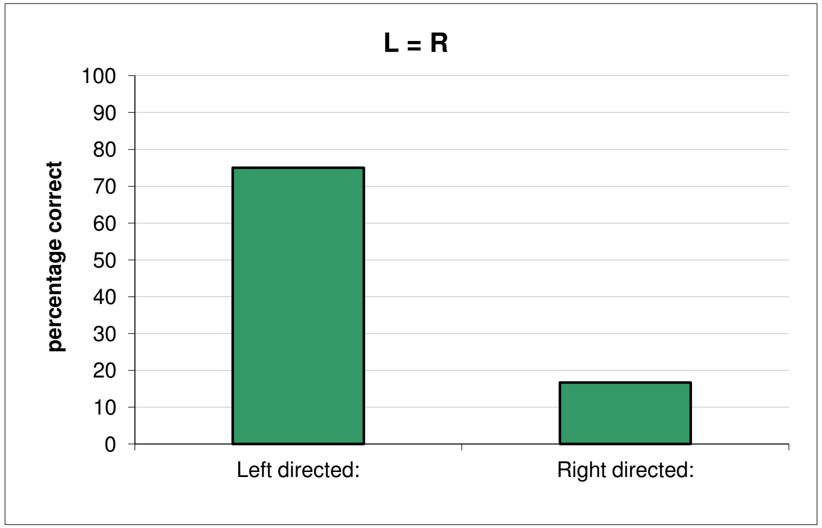
Participant 21



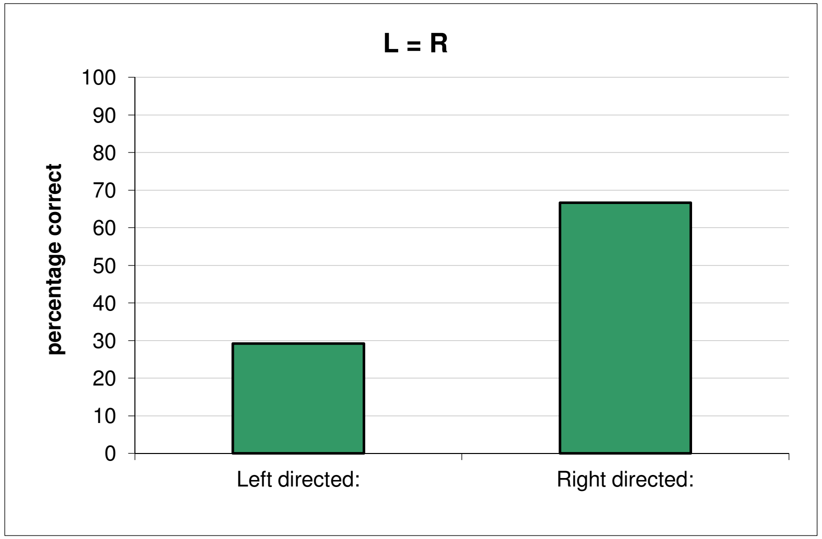
Participant 22



Participant 23



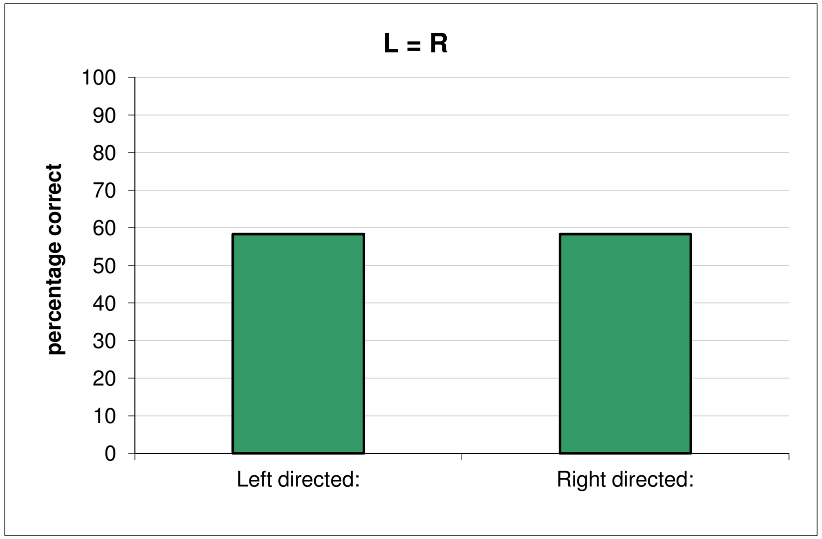
Participant 24



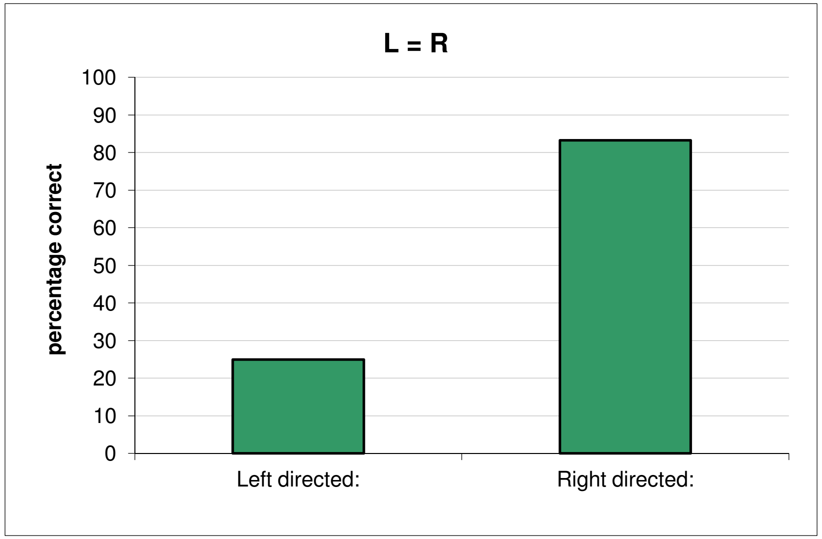
Participant 25

Appendix XVIII

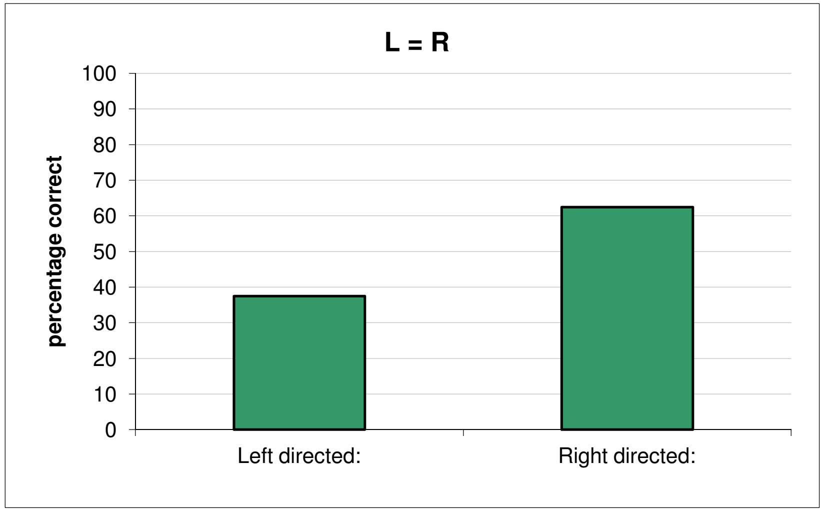
Individual Results of Female Participants in Group 3 (55-64 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



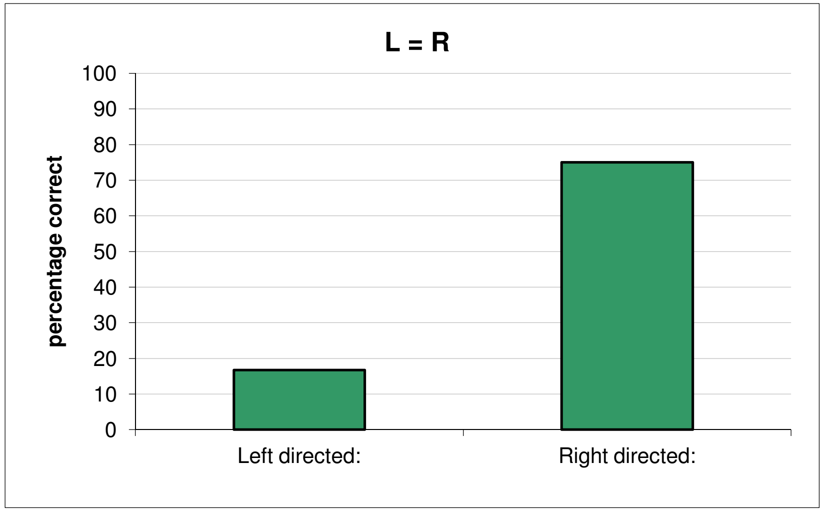
Participant 26



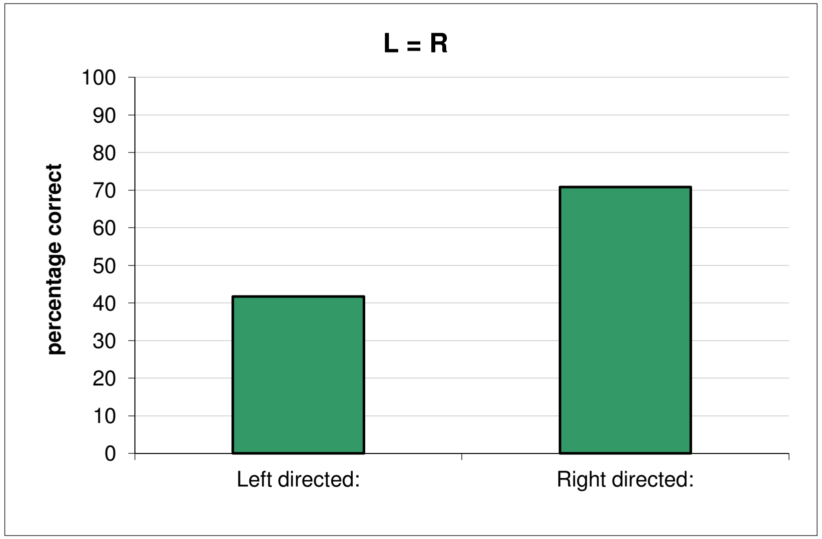
Participant 27



Participant 28



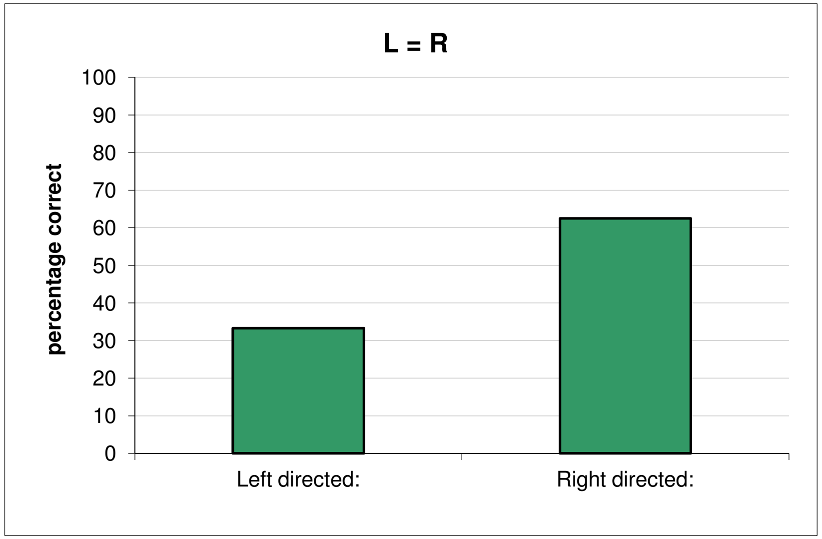
Participant 29



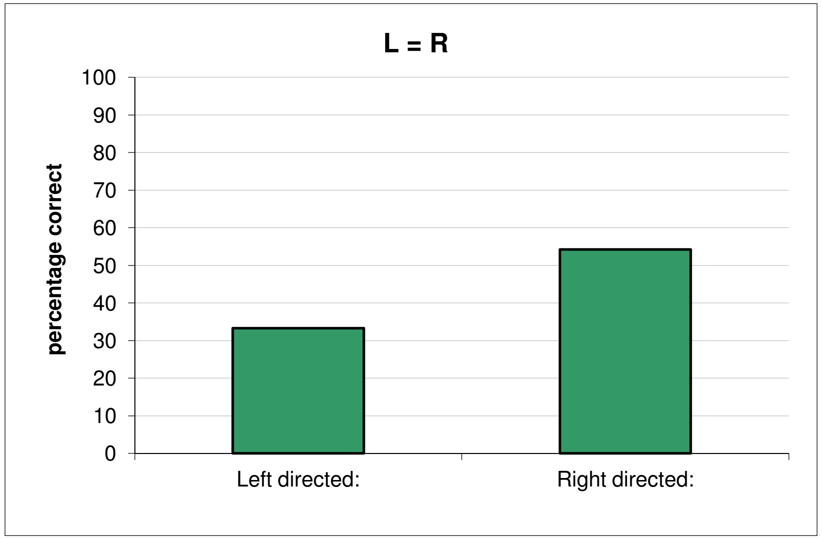
Participant 30

Appendix XIX

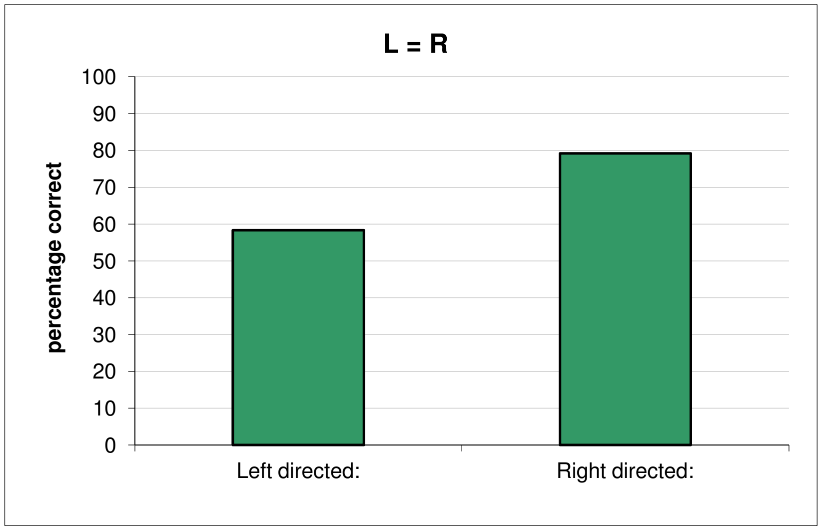
Individual Results of Male Participants in Group 4 (65-74 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



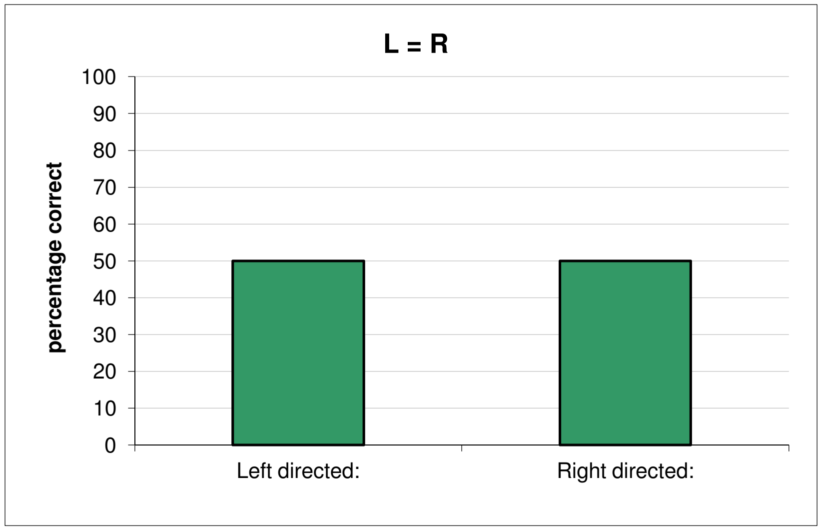
Participant 31



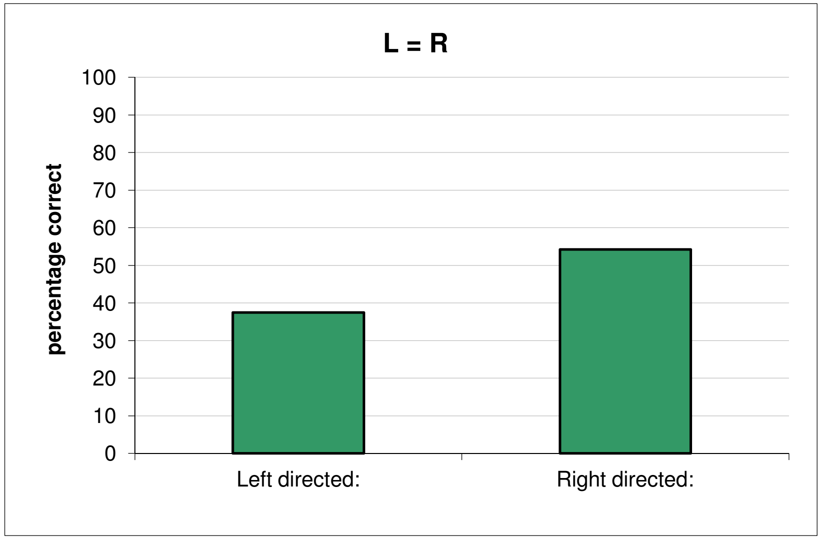
Participant 32



Participant 33



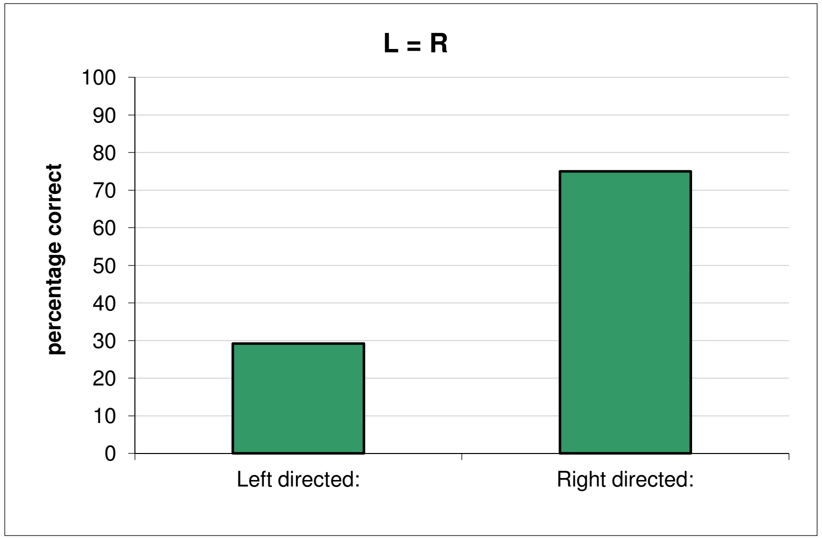
Participant 34



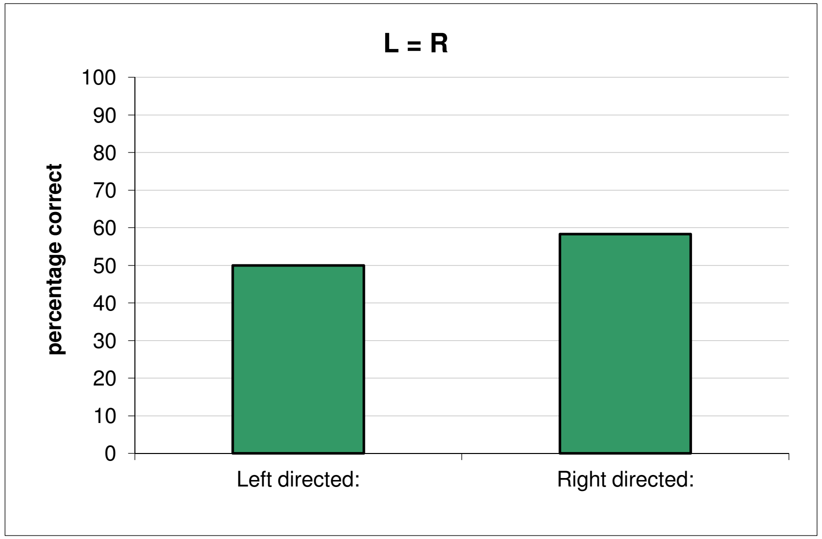
Participant 35

Appendix XX

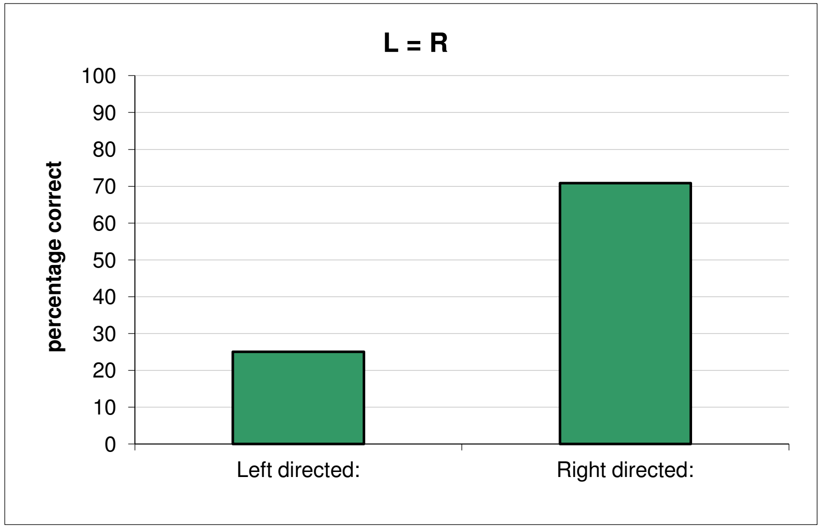
Individual Results of Female Participants in Group 4 (65-74 years) in the Directed Attention Dichotic Listening Task. Participants are numbered according to Table 1



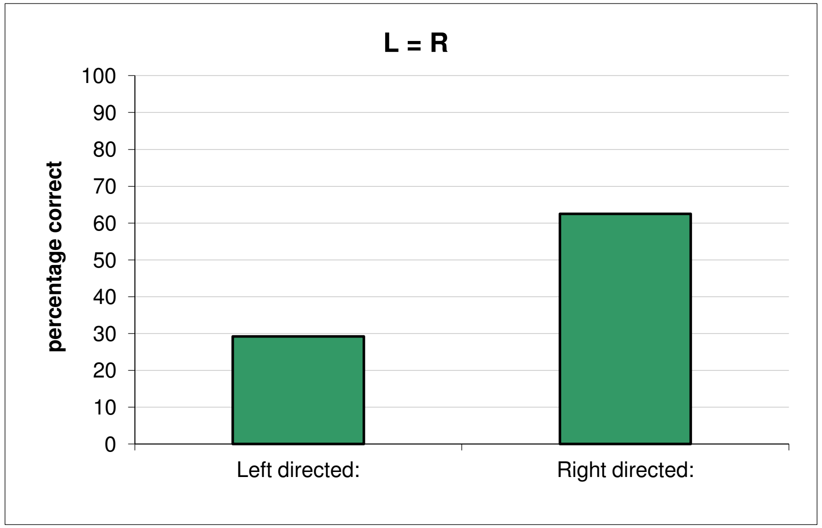
Participant 36



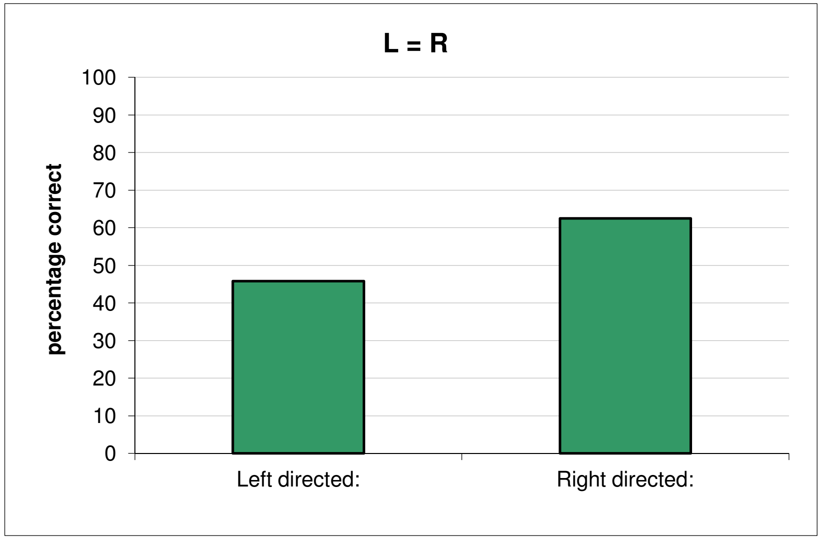
Participant 37



Participant 38



Participant 39



Participant 40